Basic sensory methods for food evaluation

B.M. Watts, G.L. Ylimaki, L.E. Jeffery, L.G. Elias

The International Development Research Centre is a public corporation created by the Parliament of Canada in 1970 to support research designed to adapt science and technology to the needs of developing countries. The Centre's activity is concentrated in six sectors: agriculture, food, and nutrition sciences; health sciences; information sciences; social sciences; earth and engineering sciences; and communications. IDRC is financed solely by the Parliament of Canada; its policies, however, are set by an international Board of Governors. The Centre's headquarters are in Ottawa, Canada. Regional offices are located in Africa, Asia, Latin America, and the Middle East.

Il existe également une version française de cette publication.
La edición española de esta publicación también se encuentra disponible.

IDRC-277e

BASIC SENSORY METHODS

FOR FOOD EVALUATION

B. M. Watts
G. L. Ylimaki
L. E. Jeffery
Department of Foods & Nutrition,
Faculty of Human Ecology,
University of Manitoba,
Winnipeg, Manitoba.
Canada

L. G. Elias
Institute of Nutrition of
Central America and Panama,
Guatemala City,
Guatemala,
Central America

Prepared with the support of
The International Development Research Centre,
Ottawa, Canada

90-03221/

© International Development Research Centre 1989
PO Box 8500, Ottawa, Ontario, Canada K1G 3H9

Watts, B.M.
Ylimaki, G.L.
Jeffery, L.E.
Elias, L.G.

IDRC-277e
Basic sensory methods for food evaluation. Ottawa, Ont., IDRC, 1989. x + 160 p. : ill.

/Testing/, /food technology/, /agricultural products/, /consumer behaviour/, /nutritive value/ — /planning/, /group discussion/, /work environment/, /hand tools/, /statistical analysis/, /manuals/.

UDC: 664.001.5:339.4

ISBN: 0-88936-563-6

A microfiche edition is available.

This work was carried out with the aid of a grant from the International Development Research Centre. The views expressed in this publication are those of the authors and do not necessarily represent those of IDRC, the Department of Foods and Nutrition at the University of Manitoba, or the Institute of Nutrition of Central America and Panama. Mention of a proprietary name does not constitute endorsement of the product and is given only for information.

CONTENTS

FOREWORD ix

PREFACE 1

INTRODUCTION 5

Chapter 1 Using Product-oriented and Consumer-oriented Testing 7

1.1 CONSUMER-ORIENTED TESTING 8
1.2 PRODUCT-ORIENTED TESTING 9

Chapter 2 Designing Sensory Testing Facilities 11

2.1 PERMANENT SENSORY FACILITIES 11
  2.1.1 Food Preparation Area 12
  2.1.2 Panel Discussion Area 13
  2.1.3 Panel Booth Area 14
  2.1.4 Office Area 18
  2.1.5 Supplies for Sensory Testing 19

2.2 TEMPORARY SENSORY FACILITIES 23
  2.2.1 Food Preparation Area 23
  2.2.2 Panel Area 25
  2.2.3 Desk Area 25
  2.2.4 Supplies for Sensory Testing 25

2.3 DESIGN OF A SIMPLE SENSORY TESTING LABORATORY 26

Chapter 3 Establishing Sensory Panels 29

3.1 RECRUITING PANELISTS 29
3.2 ORIENTING PANELISTS 30
3.3 SCREENING PANELISTS FOR TRAINED PANELS . 31
3.4 TRAINING PANELISTS 32
3.5 MONITORING PANELISTS' PERFORMANCE 33
3.6 MOTIVATING PANELISTS 35

Chapter 4 **Conducting Sensory Tests** 37

4.1 SAMPLING FOOD FOR SENSORY TESTING 37
4.2 PREPARING SAMPLES FOR SENSORY TESTING 38
4.3 PRESENTING SAMPLES FOR SENSORY TESTING 39
4.4 USING REFERENCE SAMPLES 41

Chapter 5 **Reducing Panel Response Error** 43

5.1 EXPECTATION ERRORS 43
5.2 POSITIONAL ERRORS 44
5.3 STIMULUS ERRORS 45
5.4 CONTRAST ERRORS 45

Chapter 6 **Collecting and Analyzing Sensory Data** 47

6.1 MEASUREMENT SCALES 47
  6.1.1 Nominal Scales 48
  6.1.2 Ordinal Scales 48
  6.1.3 Interval Scales 49
  6.1.4 Ratio Scales 51

6.2 STATISTICAL ANALYSIS 52

6.3 STATISTICAL TESTS 54
  6.3.1 Statistical Tests for Scalar Data 54

6.4 EXPERIMENTAL DESIGN 56
  6.4.1 Randomization 57
  6.4.2 Blocking 57
  6.4.3 Replication 58

Chapter 7 **Sensory Tests: Descriptions and Applications** 59

7.1 CONSUMER-ORIENTED TESTS 60
- 7.1.1 Preference Tests 60
- 7.1.2 Acceptance Tests 63
- 7.1.3 Hedonic Tests 66

7.2 PRODUCT-ORIENTED TESTS 79
- 7.2.1 Difference Tests 79
- 7.2.2 Ranking for Intensity Tests 86
- 7.2.3 Scoring for Intensity Tests 90
- 7.2.4 Descriptive Tests 104

Chapter 8 **Planning a Sensory Experiment** 105

APPENDICES 107

- Appendix 1 Basic Taste Recognition Test 109
- Appendix 2 Basic Odour Recognition Test 111
- Appendix 3 Training and Monitoring a Bean Texture Panel 114
- Appendix 4 Techniques for Evaluating Textural Characteristics of Cooked Beans 116
- Appendix 5 Food References Used for Bean Texture Panels 117
- Appendix 6 Line Scale Ballot Used for Bean Texture Panels 118
- Appendix 7 Statistical Tables 119

REFERENCES 137

GLOSSARY 145

INDEX 157

LIST OF FIGURES

Figure 1 Panel Discussion Area with Panel Booth Constructed Along One Wall 15

Figure 2 Panel Booths with Individual Sections for Each Panelist 16

Figure 3 Disposable Sample Containers 21

Figure 4 Reusable Sample Containers 22

Figure 5 Typical Sample Tray Set-up for Presentation to a Panelist 24

Figure 6 Plan of a Simple Sensory Testing Laboratory Located at INCAP, Guatemala 27

Figure 7 Examples of Commonly Used Sensory Scales 50

Figure 8 Ballot for Bean Puree Paired-Preference Test 63

Figure 9 Ballot for Bean Texture Acceptability Ranking Test 64

Figure 10 Ballot for Bean Varieties Hedonic Test Using a 9-Point Scale 71

Figure 11 Ballot for Bean Storage Pretreatment Triangle Test 85

Figure 12 Ballot for Seedcoat Toughness Ranking Test 88

Figure 13 Ballot for Bean Hardness Scoring Test Using a Line Scale 92

LIST OF TABLES

Table 1 Tabulated Ranking for Acceptance Test Data 67

Table 2 Tabulated Category Scores for the Hedonic Test 73

Table 3 ANOVA Table for the Hedonic Test 75

Table 4 Six Possible Serving Orders for a Triangle Test 82

Table 5 Tabulated Triangle Test Data 84

Table 6 Tabulated Ranking for Intensity Test Data 89

Table 7 Tabulated Scoring for Hardness Test Data 93

Table 8 ANOVA Table I Scoring for Hardness Test 98

Table 9 Data Matrix of Treatment Totals for Each Panelist 98

Table 10 ANOVA Table II Scoring for Hardness Test 100

LIST OF STATISTICAL TABLES

Appendix Table 7.1
Random Numbers Table 121

Appendix Table 7.2
Two-Tailed Binomial Test 123

Appendix Table 7.3
Critical Absolute Rank Sum Differences for "All Treatment" Comparisons at 5% Level of Significance 124

Appendix Table 7.4
Critical Absolute Rank Sum Differences for "All Treatment" Comparisons at 1% Level of Significance 125

Appendix Table 7.5
F Distribution at 5% Level of Significance 126

Appendix Table 7.6
F Distribution at 1% Level of Significance 128

Appendix Table 7.7
Critical Values (Q Values) for Duncan's New Multiple Range Test at 5% Level of Significance 130

Appendix Table 7.8
Critical Values (Q Values) for Duncan's New Multiple Range Test at 1% Level of Significance 132

Appendix Table 7.9
One-Tailed Binomial Test 134

Appendix Table 7.10
Percentage Points of the Studentized Range Upper 5% Points 135

Appendix Table 7.11
Percentage Points of the Studentized Range Upper 1% Points 136

FOREWORD

This manual is intended to provide a basic technical guide to methods of sensory evaluation. It has been compiled particularly with the needs of scientists in developing countries in mind. They, unlike their counterparts in industrialized countries, often lack adequate facilities and access to information sources.

The selection of materials included in this guide has been influenced by the experience of the authors in setting up and implementing sensory evaluation testing at the Institute of Nutrition of Central America and Panama (INCAP) in Guatemala. This experience was supported, in part, by the International Development Research Centre (IDRC) through a research project on beans that was intended to address problems of storage hardening, lengthy preparation time, and nutritional availability. The authors are to be congratulated on the production of a comprehensive, practical guide.

In supporting food- and nutrition-related research, IDRC gives a high priority to ensuring that any new or modified products and processes take full account of the likes, dislikes, and preferences of the target consumer groups, and their acceptability requirements. The objective is to help maximize the likelihood of achieving a positive effect, particularly on disadvantaged producers, processors, and consumers.

It is hoped that this manual will be usful to a wide variety of readers, including researchers, students, government control agencies, and others dealing with issues of more efficient and effective food production and use within the context of clearly identified consumer preferences and requirements.

Geoffrey Hawtin
Director
Agriculture, Food and Nutrition Sciences Division
IDRC

PREFACE

This manual arose from the need to provide guidelines for sensory testing of basic agricultural products in laboratories where personnel have minimal or no training in sensory analysis. It is the outcome of a collaborative project between the Department of Foods and Nutrition, University of Manitoba and the Institute of Nutrition of Central America and Panama (INCAP). Included are discussions of sensory analysis principles, descriptions of sensory testing facilities and procedures, and examples of statistical treatment of sensory test data. Examples presented have been drawn from studies of the sensory characteristics and acceptability of black beans. These studies were conducted as part of a bean research network, funded by the International Development Research Centre (IDRC) to increase the availability, consumption and nutritive value of beans, an important staple food in Latin America. Principles discussed, however, apply to the evaluation of many other types of food and the methods described can be used to measure and compare the sensory characteristics of both agricultural commodities and processed foods.

This publication has been designed to provide an introduction to sensory methods. For more thorough discussions of sensory techniques the reader is referred to recent books by Meilgaard *et al.* (1987), Jellinek (1985), Stone and Sidel (1985) and Piggott (1984), to the ASTM publications STP 758 (1981), STP 682 (1979), STP 434 (1968) and STP 433 (1968), and to the classical work on sensory analysis by Amerine *et al* (1965). The concise and widely used *Laboratory Methods for Sensory Evaluation of Foods* (Larmond, 1977) is also highly recommended. Statistical methods for sensory data analysis have been explained in detail in books by O'Mahony (1986) and Gacula and Singh (1984). Basic statistical principles and methods are provided in many statistics books such as those by Snedecor and Cochran (1980), and Steel and Torrie (1980).

The support of this project provided by the International Development Research Centre, Ottawa, by the Institute of Nutrition of Central America and Panama, Guatemala City, and by the Department of Foods and Nutrition of the University of Manitoba, Winnipeg, is gratefully acknowledged. Thanks are due to many individuals in each of these institutions for their encouragement and assistance at each stage in the preparation of this work. The authors are particularly indebted to the staff and students at the Institute of Nutrition, and the University of Manitoba, who served as panelists during the sensory experiments used as examples in this book. Valuable editorial suggestions were made by Linda Malcolmson and Marion Vaisey-Genser of the University of Manitoba, by Gabriella Mahecha of the National University of Colombia, Bogota, and by Dorien van Herpen of the Centro International de Agricultura Tropical (CIAT), Cali, Colombia. The assistance of the Statistical Advisory Service of the University of Manitoba is also greatly appreciated. Special thanks are expressed to Angela Dupuis, Bill Lim, Derrick Coupland, and

Horst Weiss for typing, designing and illustrating the manuscript. Thanks are also extended to the peer reviewers of the manuscript for their useful suggestions. Support and encouragement were provided by many other colleagues and friends, who cannot be mentioned by name, but whose contributions are remembered with gratitude by the authors.

Beverly Watts
Gladys Ylimaki
Lois Jeffery
Luis G. Elias

INTRODUCTION

Sensory analysis is a multidisciplinary science that uses human panelists and their senses of sight, smell, taste, touch and hearing to measure the sensory characteristics and acceptability of food products, as well as many other materials. There is no one instrument that can replicate or replace the human response, making the sensory evaluation component of any food study essential. Sensory analysis is applicable to a variety of areas such as product development, product improvement, quality control, storage studies and process development.

A sensory panel must be treated as a scientific instrument if it is to produce reliable, valid results. Tests using sensory panels must be conducted under controlled conditions, using appropriate experimental designs, test methods and statistical analyses. Only in this way can sensory analysis produce consistent and reproducible data.

✦ *Chapter 1*

Using Product-oriented and Consumer-oriented Testing

Consumers' sensory impressions of food begin in the marketplace where visual, odour and tactile senses, and perhaps taste are used in food selection. During food purchasing, preparation and consumption, the product cost, packaging, uncooked and cooked appearance, and ease of preparation influence consumers' total impression of a food. However, sensory factors are the major determinant of the consumer's subsequent purchasing behaviour.

Information on consumer likes and dislikes, preferences, and requirements for acceptability can be obtained using consumer-oriented testing methods and untrained sensory panels. Information on the specific sensory characteristics of a food must be obtained by using product-oriented tests. The development of new food products or the reformulation of existing products, the identification of changes caused by processing methods, by storage or by the use of new ingredients, and the maintenance of quality control standards all require the identification and measurement of sensory properties. This type of product-oriented quantitative information is obtained in the laboratory using trained sensory panels. When food formulas are being altered or new formulas being developed, product-oriented testing usually precedes consumer testing.

1.1 CONSUMER-ORIENTED TESTING

In true consumer testing a large random sample of people, representative of the target population of potential users, is selected to obtain information on consumers' attitudes or preferences. Consumer panelists are not trained or chosen for their sensory acuity, but should be users of the product. For this type of testing 100 to 500 people are usually questioned or interviewed and the results utilized to predict the attitudes of the target population. Interviews or tests may be conducted at a central location such as a market, school, shopping mall, or community centre, or may take place in consumers' homes. Because a true consumer test requires selection of a panel representative of the target population, it is both costly and time consuming. Therefore untrained in-house consumer panels are commonly used to provide initial information on product acceptability and often are conducted prior to true consumer tests. In-house panels are much easier to conduct than true consumer tests and allow for more control of testing variables and conditions. In-house panels are, however, meant to augment, not replace, true consumer tests.

In-house consumer panels (pilot consumer panels) usually consist of 30 to 50 untrained panelists selected from personnel within the organization where the product development or research is being conducted. A group of panelists who are similar to the target population of consumers who use the product should be chosen. It is advantageous to use as large a panel as possible. This type of panel can indicate the relative acceptability of products, and can identify product defects. Results from in-house consumer testing should not be used to predict product performance in the marketplace, however, because in-house panels may not be representative of the actual consuming population.

1.2 PRODUCT-ORIENTED TESTING

Product-oriented testing uses small trained panels that function as testing instruments. Trained panels are used to identify differences among similar food products or to measure the intensities of flavour (odour and taste), texture or appearance characteristics. These panels usually consist of 5-15 panelists who have been selected for their sensory acuity and have been specially trained for the task to be done. Trained panelists should not be used to assess food acceptability. Their special training makes them more sensitive to small differences than the average consumer and teaches them to set aside personal likes or dislikes when measuring sensory parameters.

◆ *Chapter 2*

Designing Sensory Testing Facilities

Sensory testing does not require elaborate facilities but some basic requirements must be met if tests are to be conducted efficiently and results are to be reliable. Although permanent facilities, specially designed for sensory testing, will provide the best testing environment, existing laboratory space can be adapted for sensory use. The basic requirements for all sensory testing facilities are (1) a food preparation area, (2) a separate panel discussion area, (3) a quiet panel booth area, (4) a desk or office area for the panel leader, and (5) supplies for preparing and serving samples.

2.1 PERMANENT SENSORY FACILITIES

The design of permanent sensory testing facilities and illustrations of possible layouts for sensory laboratories have been presented in books by Jellinek (1985), Larmond (1977), Stone and Sidel (1985) and ASTM publication STP 913 (1986). The types of tests to be conducted, the amount of testing to be done, the space and resources available, will be deciding factors in the design of the laboratory.

Throughout the sensory area, walls should be painted in neutral colours. Odour-free surface materials should be used in construction of floors and counter tops. Some woods, rugs and plastics emit odours which interfere with the sensory evaluations, and should therefore be avoided.

2.1.1 Food Preparation Area

The area for food preparation should contain counters, sinks, cooking and refrigeration equipment and storage space. The area should be well lit and ventilated.

Counters. Sufficient counter area is needed to provide working space for food preparation, and to hold prepared trays of samples before they are given to the panelists. A counter height of approximately 90 cm (36 inches) is comfortable for working. Standard counter depth is approximately 60 cm (or 24 inches).

Sinks. At least two sinks with hot and cold running water should be provided. It is also useful to have a source of distilled water in the sensory laboratory. If tap water imparts odours or flavours, distilled water should be used for panelists' rinse water, cooking and rinsing dishes.

Cooking equipment. Gas or electric stoves or separate heating elements and ovens should be provided. Microwave ovens may also be a useful addition to the food preparation area.

Refrigeration equipment. Refrigerated storage is essential for keeping perishable foods and may be needed to chill samples to a constant low temperature before serving. A separate freezer can be useful for long term storage of ingredients, for storage of reference samples and to enable foods prepared at different times to be stored and evaluated together.

Storage space. Cupboards or closed shelves for dish and supply storage should be constructed under the working counters and also over the pass-through openings to the panel area. An open shelf over the pass-through area is useful for holding prepared trays during panel set up. Drawers directly under the counters are convenient for storing napkins, pencils, plastic spoons and forks and similar panel supplies.

Ventilation. Ventilation hoods with exhaust fans should be installed over the stoves to reduce cooking odours in the preparation area and to prevent spreading of these odours to the panel room.

2.1.2 Panel Discussion Area

For product-oriented testing it is necessary to have a room where the panelists can meet with the panel leader for instruction, training and discussion. This discussion area should be completely separate from the food preparation area so that noise and cooking odours do not interfere with the panelists' tasks. It should be located so that there are no interruptions from other laboratory personnel. A comfortable well lit area, with a large table and chairs or stools to seat at least 10 people, is ideal. A large chalkboard, flip chart, or white board should be located where it can be easily seen by the panelists around the table. A bulletin board located close to the entrance allows posting of notices and information about panelists' performance. An example of a panel discussion area is shown in Figure 1.

2.1.3 Panel Booth Area

The booth area, like the discussion area, should be completely separate from the food preparation area. Although it is preferable to have a self-contained panel booth room, areas can be combined by having the booths constructed along one wall of the group discussion room, with no dividing wall between the booth and discussion areas, as shown in Figure 1. However, group discussions cannot then be held simultaneously with individual tasting sessions. This arrangement could create a problem if several sensory tasks are under way at one time.

The panel booth area should contain individual compartments where panelists can assess samples without influence by other panel members (Figure 2). This area may contain as few as 4 individual sections but 5 to 10 are most common. Each booth should be equipped with a counter, a stool or chair, a pass-through opening to the food preparation area and individual lighting and electrical outlets. While sinks in panel booths may appear useful for expectoration, they can cause odour and sanitation problems and are not recommended.

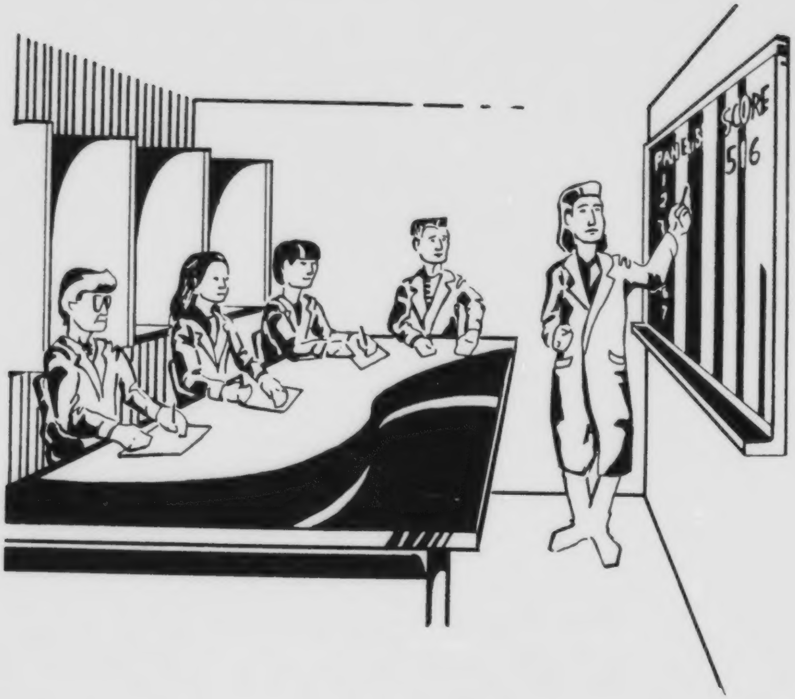

PANELISTS
SCORE
1
2
3
5
6
6
7

Figure 1   Panel discussion area with panel booth constructed along one wall

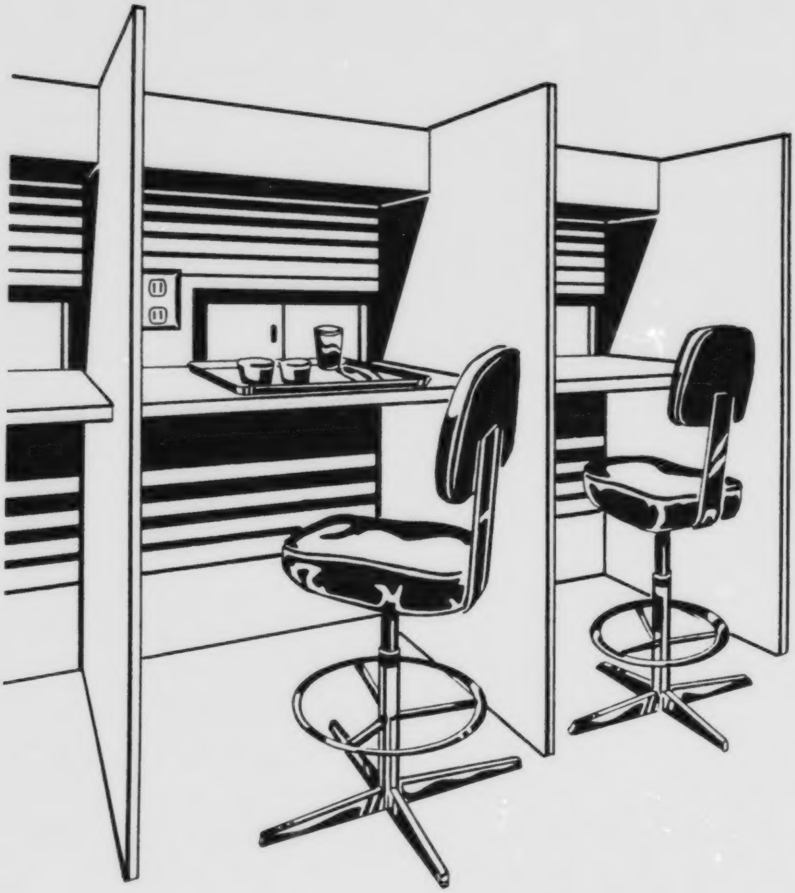


Figure 2 Panel booths with individual sections for each panelist

It is useful to have the entrance to the panel area within partial view of the food preparation facilities. The panel leader can then see when panelists arrive and can supervise activities in both the food preparation and panel rooms.

Panel booths. Panel booths can be constructed with permanent dividers or can consist of a countertop with movable partitions. Each booth should be approximately 60 cm (24") in depth and be a minimum of 60 cm (24") in width, but the preferred width is 76-86 cm (30-34"). The booth counter should be the same height as the counter on the food preparation side of the pass-through to allow sample trays to be passed from one side to the other with ease. This may be desk height, 76 cm (30") or counter height, approximately 90 cm (36"). Counter height is usually more convenient and useful for the food preparation area. Partitions between the booths should be at least 90 cm (36") high and should extend approximately 30 cm (12") beyond the edge of the countertop to provide privacy for each panelist.

Chairs or stools. Chairs must be the appropriate height so that panelists can sit comfortably at the 76 or 90 cm (30 or 36") counter. Adequate space must be provided from the edge of the counter to the back wall of the booth area to allow chairs to be moved back and forth, and panelists to enter and leave while others are doing evaluations. A minimum distance of 90 cm (36") is required.

Pass-throughs. Each booth should have a pass-through from the food preparation area to allow samples and trays to be passed to panelists directly. The pass-through opening should be approximately 40 cm (16") wide, 30 cm (12") high, and should be flush with the counter top. The opening can be fixed with a sliding, hinged or flip-up door. Sliding doors must be well fitted or they may stick and cause problems. Hinged or flip-up doors require a lot of clear counter space to work properly.

Lighting and electrical outlets. Each booth should have individual overhead lighting so that the light distribution is uniform from one booth to another. Incandescent or fluorescent lighting may be used. Incandescent lighting offers a range of illumination but is more costly to install and maintain than fluorescent lighting. Fluorescent lights can be obtained in cool white, warm white or simulated daylight. Day light tubes are recommended for food testing. Lights of various colours such as red and yellow should be installed, in addition to the conventional white lights. These can be used to mask colour differences between food samples. Flood lights with removable plastic coloured filters provide an economical means of controlling light colour. Each booth should have an electrical outlet so that warming trays can be used.

Ventilation. The panel room should be adequately ventilated and maintained at a comfortable temperature and humidity. The ventilation system should not draw in odours from the cooking area. If the building in which the sensory facilities are being installed has air conditioning, then positive air pressure may be maintained in the panel booth area to prevent infiltration of external odours.

2.1.4 Office Area

In addition to the space needed for the actual sensory testing, a place where the panel leader can prepare ballots and reports, analyze data and store results is required. This area should be equipped with a desk, a filing cabinet, and either a statistical calculator or a computer equipped with a statistical program for data analysis.

2.1.5 Supplies for Sensory Testing

The sensory areas should be equipped with utensils for food preparation and with equipment and small containers for serving samples to the panelists. All utensils should be made of materials that will not transfer odours or flavours to the foods being prepared or sampled. Food preparation and serving equipment, utensils and glassware for the sensory testing area should be purchased new and used exclusively for sensory testing. Food items, sample containers (particularly the disposable ones), rinse cups and utensils, should be purchased in large quantities, sufficient to last throughout an entire study.

Utensils for food preparation. An accurate balance or scale, graduated cylinders, pipettes, volumetric flasks and glass beakers of various sizes will be needed to make precise measurements during food preparation and sampling. Glass (*i.e.* Pyrex) or glass-ceramic (*i.e.* Corningware) cooking pots should be selected rather than metal cookware because glass and glass-ceramic containers are less likely to impart flavours or odours to the foods cooked in them. If only metal is available, then stainless steel is a better choice than aluminum, tin or cast iron cookware. Thermometers and standard kitchen utensils such as sieves and strainers, can openers, knives, forks, spoons, bowls, pot holders and covered storage containers will also be needed.

Sample containers. Sample containers should be chosen according to the sample size and characteristics. The size of the containers will vary with the type of product being tested and with the amount of sample to be presented. Disposable paper, plastic or styrofoam containers of 30-60 mL (1-2 oz) size with lids (Figure 3), disposable petri-plates and paper plates are convenient but may prove costly. Reusable containers such as glasses, shot glasses, glass egg cups, small beakers, glass custard cups, bottles, glass plates or petri-plates (Figure 4) and glass jars are suitable alternatives. Lids or covers of some sort are necessary to protect the food samples from drying out or changing in temperature or appearance, and to prevent dust or dirt from contaminating the samples. Lids are particularly important when odours of the food samples are being evaluated. Lids allow the volatiles from the sample to build up in the container so that the panelist receives the full impact of the odour when bringing the sample container to the nose and lifting the lid.

When purchasing sample containers it is important to check that the containers do not have any odours of their own which may interfere with the evaluation of the food products. Enough containers of one size and shape must be purchased to ensure that identical containers can be used for all samples served during one study.

Trays. Plastic or metal trays, to hold the samples to be served to each panelist, should be provided. Individual electric warming trays for each booth are recommended for samples served warm. Placing samples in a water bath on the warming trays may distribute the heat more evenly than placing samples directly on the trays. Alternatively, samples may be kept warm in a thermos or warming oven in the preparation area until just before serving. In all cases, sample containers that will not melt or allow water into

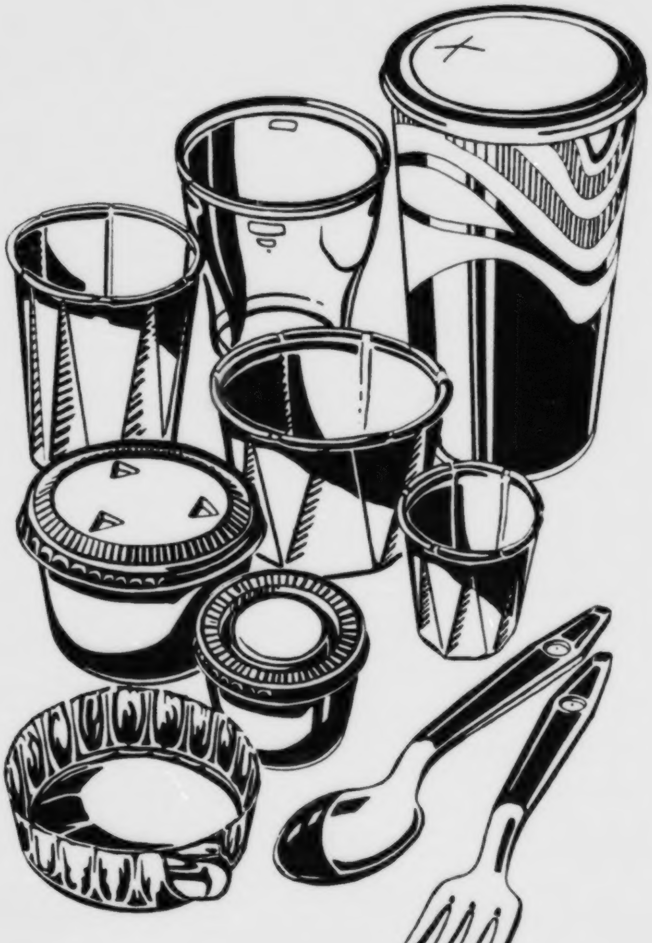


Figure 3 Disposable sample containers

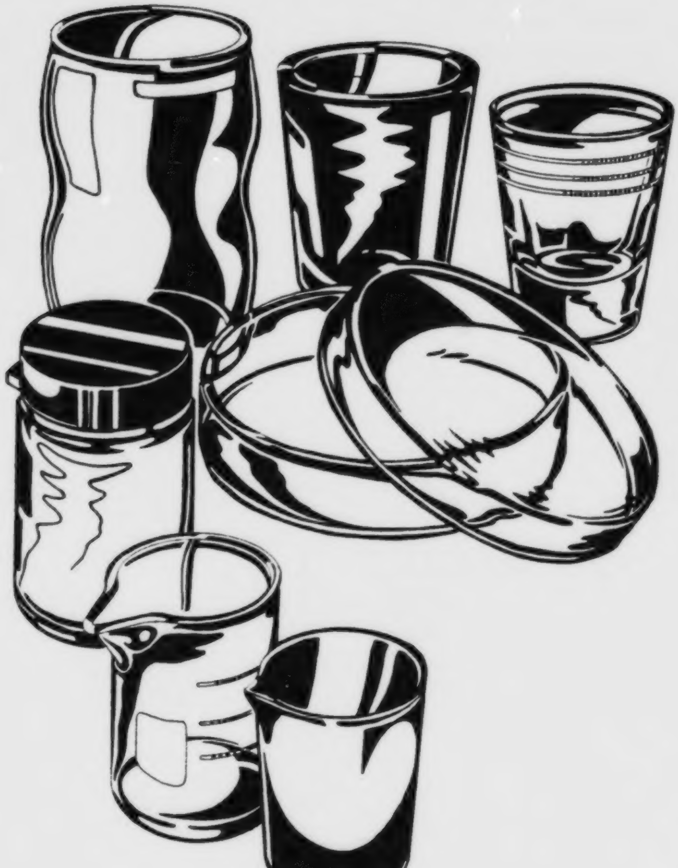


Figure 4 Reusable sample containers

the samples, are required. Styrofoam containers with lids provide an inexpensive means of keeping samples warm for short periods of time.

Additional supplies. Plastic spoons, forks and knives, napkins, disposable or glass cups for water and expectoration, and large jugs or pitchers, preferably glass, for drinking water will also be needed. A typical sample tray set-up, for presentation to a panelist, is shown in Figure 5. Odourless dishwashing detergent is suggested for washing equipment.

2.2 TEMPORARY SENSORY FACILITIES

When an area specifically designed for sensory testing is not available, or when panels, such as consumer panels, are conducted away from the permanent facility, a temporary area can be arranged to satisfy the basic requirements for sensory testing.

2.2.1 Food Preparation Area

Temporary cooking facilities can be set up in a laboratory using hotplates, and styrofoam containers can be used to keep food warm for short periods. Prepared trays can be set out on carts when counter space is limited.

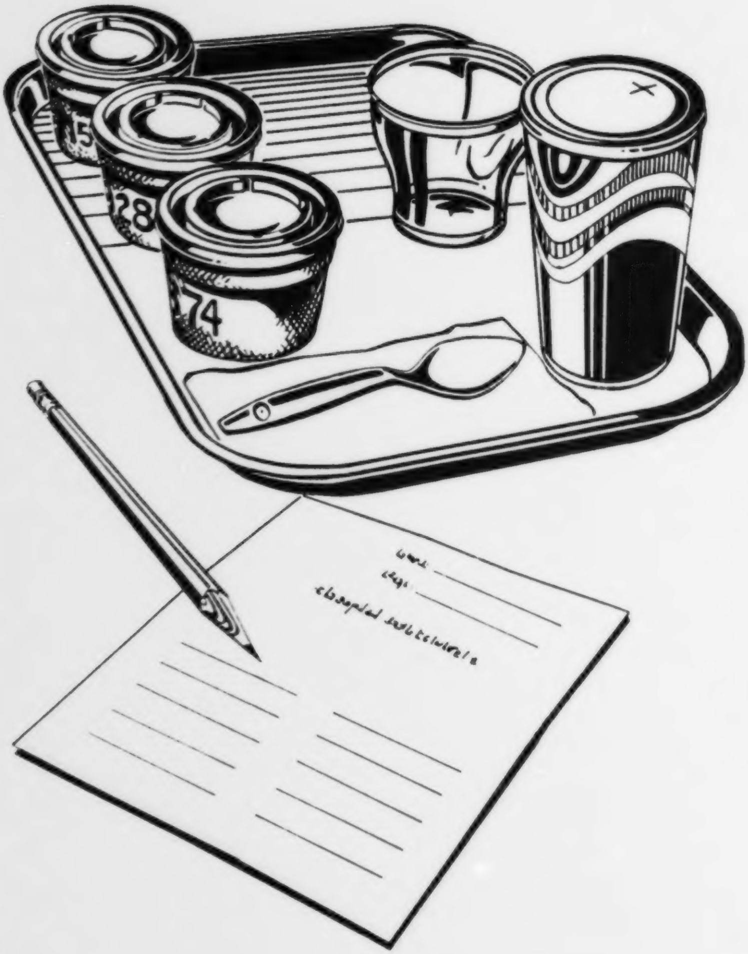


Figure 5 Typical sample tray set-up for presentation to a panelist

2.2.2 Panel Area

Samples can be presented for evaluation in any separate area where distractions, noise and odours can be kept to a minimum. A lunch or coffee room which is not in use at the times when sensory tests are to be carried out might serve adequately if food odours have cleared. To provide some privacy for the panelists, and to minimize distractions, portable partitions of light weight wood or heavy cardboard can be constructed to sit on table tops between panelists.

2.2.3 Desk Area

The panel leader will need space for preparing ballots, planning sensory tests, and analyzing data, and will need access to a calculator with statistical capabilities.

2.2.4 Supplies for Sensory Testing

The same supplies will be needed as were outlined for the permanent facility.

2.3 DESIGN OF A SIMPLE SENSORY TESTING LABORATORY

At INCAP in Guatemala City, a sensory laboratory containing panel booths and a discussion area was built adjacent to an existing kitchen facility (Figure 6). This food preparation area was already well equipped with stoves, sinks, refrigerators, storage cupboards and counter space.

In the newly designed sensory facility, panel booths are accessible from the kitchen area via pass-throughs with horizontal sliding doors. The five panel booths are open from the back to the group discussion area which is equipped with a large table, and with stools to seat 12-15 people. Each booth has individual light fixtures and an electrical outlet. The divisions between the booths are hinged so that they can be folded to one side if clear counter space is needed on some occasions.

Although a separate office for the panel leader was not available, a desk placed in the food preparation area provides space for preparing ballots and analyzing data.

The following items were acquired to equip the sensory laboratory at INCAP:

- 1 analytical balance
- glassware (graduated cylinders and beakers of various sizes)
- 5 electric warming trays with adjustable thermostats (1 per panel booth)
- 8 - 3 L glass cooking pots with lids
- 10 - 300 mL plastic storage containers with lids

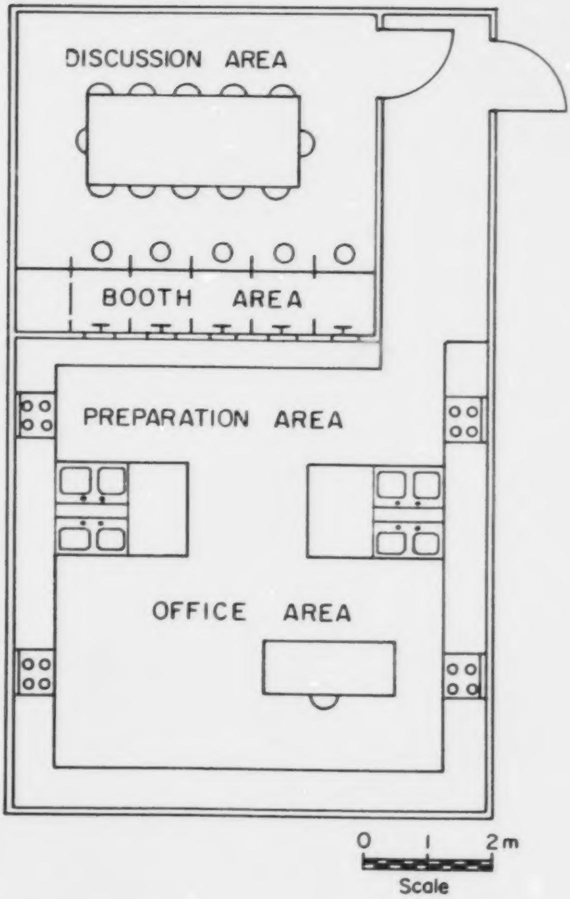

DISCUSSION AREA
BOOTH AREA
PREPARATION AREA
OFFICE AREA
0
1
2 m
Scale

Figure 6 Plan of a simple sensory testing laboratory located at INCAP, Guatemala

- 20 - 15 cm diameter styrofoam containers with lids (tortilla holders)
- 15 white plastic serving trays
- 6 large water jugs
- 48 - 50 mL red sample glasses with tin foil lids
- disposable 75 mL plastic cups for water and for expectoration
- disposable 30 mL plastic sample containers with lids
- disposable 30 mL styrofoam sample cups with lids
- disposable white plastic teaspoons
- paper napkins
- pot holders, tea towels, spoons, forks, knives, strainers, paper towels, detergent
- statistical calculator

◆ *Chapter 3*

Establishing Sensory Panels

The testing instrument for sensory analysis is the panel of human judges who have been recruited and trained to carry out specific tasks of sensory evaluation. Recruiting panelists, training them, monitoring their performance, providing leadership and motivation is the job of the panel leader. Thorough preparation and efficient direction of the panel by the leader are essential if the panel is to function effectively.

3.1 RECRUITING PANELISTS

Panelists for both trained panels and untrained in-house panels can usually be drawn from the personnel of the institution or organization where the research is being conducted. The majority of the people within an organization are potential panelists. They will usually be interested in participation if they feel that their contribution is important.

To help with panelist recruitment, all potential panelists should be asked to complete questionnaires giving their food likes and dislikes, indicating their level of interest in the project to be carried out, listing any food restrictions or allergies they may have and giving times when they would be available for panels. This information will help the panel leader to select those individuals appropriate for the study. In a company or institution where sensory tests are conducted on a regular basis, it is useful to keep a file with information on all potential panelists. Records should also be kept on each panelist who participates in any sensory panel.

3.2 ORIENTING PANELISTS

Potential panelists should be invited to the sensory panel area, in groups of no more than 10 at a time, to allow the panel leader to explain the importance of sensory testing, show the panelists the testing facilities, and answer questions that may arise. Individuals participating only in in-house acceptability panels (untrained panels) do not need to be given any subsequent training. However, it is useful to demonstrate the way in which the ballots should be marked, using enlarged ballots shown on an overhead projector or a blackboard. Discussing the actual food to be tested should be avoided. Explaining the test method and procedure will reduce confusion and make it easier for panelists to complete the task. It is important that all panelists understand the procedures and score cards so they may complete the test in a similar manner.

Panelists should be advised to avoid strong odourous materials, such as soaps, lotions and perfumes prior to participating on panels and to avoid eating, drinking or smoking at least 30 minutes prior to a sensory test.

3.3 SCREENING PANELISTS FOR TRAINED PANELS

Panelists who agree to serve on trained panels should be screened for "normal" sensory acuity. This can be done by asking panelists to identify basic tastes and common odours. Instructions for conducting taste and odour identification tests are given in Appendices 1 and 2.

Panelists' sensitivity, that is their ability to discriminate between levels of a particular sensory characteristic, should also be tested. Triangle tests, using food samples or solutions that are identical for all but the level of one flavour or texture characteristic, are often used to test panelists' discrimination skills. People with a poor sense of smell or taste, or who are insensitive to differences in flavour or texture intensities, can be identified through these screening processes. For those who ultimately will serve on a trained panel, the screening process provides some preliminary sensory experience.

After the initial screening, panelists should be tested for their ability to discriminate using samples very similar or identical to those to be studied. Some panelists are excellent discriminators for one type of food product, but are poor discriminators for others.

Locating panelists sensitive to differences in the test food is important.

If 20-25 people can be screened, it should be possible to select for training, a group of 12-14 people who have demonstrated superior performance during screening sessions. Panelists chosen should also be interested in the project, and able to participate on a long term basis. Panel training takes approximately 1/2 hour a day, usually 2-4 times per week. Panel training should begin with a larger group of people than is needed for the final trained panel. Some panelists will almost certainly drop out due to illness or job-related priorities. The final trained panel should include at least 8 people with good discriminatory ability for the task to be done.

3.4 TRAINING PANELISTS

The performance of individual panelists, and of the panel as a whole, can be improved through suitable training exercises. Training should be designed to help panelists make valid, reliable judgements that are independent of personal preferences. A discussion of results, directed by the panel leader, should accompany each training exercise, so that the panelists as a group can develop consistent methods of evaluation. Training a panel for difference or ranking tests can usually be done in a few sessions. Training for quantitative analysis may require ten to twelve sessions, or even more if a large number of sensory characteristics are to be evaluated.

Final training should be conducted with food products similar to those that will be used during actual testing. Panelists should become familiar with the range of characteristic intensities that will be encountered during the study. During training the best procedures for preparing and presenting the samples can be established and the final score card or ballot can be designed.

Discussions should be held frequently, between the panelists and panel leader, to ensure that all panelists understand the task, ballot and terminology, and can distinguish the characteristics being studied. By providing precise definitions and descriptions for the evaluation of each characteristic, and by supplying food samples to demonstrate each characteristic wherever possible, consistent panelist response and agreement among panelists can be developed.

Panelists who are unsuccessful at one type of sensory task may do well on another. Their participation on subsequent panels should be encouraged, and appreciation for their work should be expressed by the panel leader.

3.5 MONITORING PANELISTS' PERFORMANCE

Panelists' performance must be monitored during training to determine the progress of the training. Subsequent training should concentrate on the samples and sample characteristics that panelists have difficulty identifying and evaluating. Training is completed when panelists are comfortable with the evaluation procedure, can discriminate among different samples repeatedly and can produce reproducible results. Superior panelists can then be identified to continue throughout the sensory study.

The panel leader monitors performance by evaluating the ability of the panel as a whole, and of the individual panelists, to discriminate differences among the samples being tested and to reproduce results consistently. For both types of evaluation, a set of different samples, which the panel leader knows to be different, must be evaluated by each panelist repeatedly on several occasions to provide the necessary data. Statistical analysis (analysis of variance - ANOVA) is used to assess the results. The panel data is analyzed to identify significant variation among panelists and among samples. Significant differences among panelists, although not unexpected, may be reduced with further training. Lack of significant differences among samples indicates the need for further training, if the panel leader knows that differences do in fact exist.

Individual panelist's results can also be analyzed. Panelists who are able to distinguish significant differences among the samples with small error mean squares in the analysis should be retained on the panel. If none of the panelists find significant differences among samples for a particular characteristic, additional training for that characteristic is indicated. Monitoring panelist performance during training is described in more detail in Appendix 3.

Panelist performance can also be monitored during the sensory study by comparing replicate judgements. This ensures that panelists continue to perform in a reliable, consistent manner and will indicate when additional re-training may be required or when panelists need further motivation.

3.6 MOTIVATING PANELISTS

Panelists who are interested in sensory evaluation, the products under evaluation and the outcome of the study will be motivated to perform better than uninterested panelists. It is important to maintain this interest and motivation throughout the study to ensure and encourage optimum panelist performance.

Feedback about their performance from day to day will provide much of the motivation for panelists, particularly during training. If there is not sufficient time during the panel sessions to discuss the previous day's results, the data can be posted on a wall chart for the panelists to see at their convenience. However, it is more beneficial if the panel leader personally discusses the results with the panelists, individually or as a group. Posted results can be missed or misinterpreted by the panelists. In addition, a small treat or refreshment (*i.e.* candies, chocolates, cookies, fruit, nuts, juice, cheese, crackers) at the end of each day's panel session is commonly used as a reward. At the end of a long series of panels a larger reward such as a small party, luncheon or small gift will let each panelist know that their contribution to the study has been appreciated.

◆ *Chapter 4*

Conducting Sensory Tests

Sensory tests will produce reliable results only when good experimental control is exercised at each step of the testing process. Careful planning and thorough standardization of all procedures should be done before the actual testing begins. Particular attention should be given to techniques used for sampling food materials, for preparing and presenting samples to the panel, and for using reference and control samples. These techniques are discussed in the following sections of the manual.

4.1 SAMPLING FOOD FOR SENSORY TESTING

All foods presented to the panelists for testing must, of course, be safe to eat. Panelists should not be asked to taste or eat any food that has become moldy, or has been treated in a way that might cause microbiological or chemical contamination. If a food, or an ingredient of the food, has been treated or stored in a way that may make it unsafe to eat, then only the odour and appearance attributes of the food can be evaluated.

When batches of food are being sampled for sensory testing samples taken should be representative of the total batch. If the portions ultimately served to the panelists are not representative of the food as a whole, results will not be valid. For a commodity such as beans, the lot to be tested should first be thoroughly mixed, then divided into four parts and a sample from each part extracted. These four samples should be recombined to form the test sample. The size of the test sample should be calculated beforehand, based on the number of portions that will be required for the panel.

4.2 PREPARING SAMPLES FOR SENSORY TESTING

Samples for sensory comparison should all be prepared by a standardized method to eliminate the possibility of preparation effects (unless, of course, preparation method is a variable of interest). Preparation steps should be standardized during preliminary testing and clearly documented before sensory testing is begun, to ensure uniformity during each testing period. When different types of beans, for example, are to be cooked and prepared for sensory analysis, factors that need to be controlled include the ratio of beans to soaking and cooking water, soaking time, size and dimensions of the cooking container, cooking rate and time, holding time before serving, and serving temperature. If samples require different cooking times, starting times can be staggered so that all samples finish cooking together. If this is not done, variations in holding time may influence sensory assessment. Holding samples for an extended period of time can drastically alter their appearance, flavour and texture.

4.3 PRESENTING SAMPLES FOR SENSORY TESTING

Methods of sample presentation should also be standardized. It is important that each panelist receive a representative portion of the test sample. Tortillas, for instance, can be cut into wedges of uniform size so that each panelist will receive part of both the edge and the centre of a tortilla. Fluid products should be stirred during portioning to maintain uniform consistency within the portions. The end crusts of breads or baked goods and the outer surface of meat samples may have to be discarded so that each panelist receives a similar portion. If bread crusts are left on samples, each panelist should receive a sample with a similar crust covering. Portions should all be of the same size. When food products consist of a number of small pieces which may differ from piece to piece, panelists should receive a portion large enough that they can evaluate a number of pieces for each characteristic. When beans, for example, are being tested for firmness, panelists should test 3-4 beans before recording their score for the firmness of the sample. In general, at least 30 grams (1 oz) of a solid food or 15 mL (0.5 oz) of a beverage should be served (ASTM STP 434, 1968).

Samples should all be presented at the same temperature, and this should be the temperature at which the food is usually consumed. Milk should be served at refrigerator temperature, but bread or cake at room temperature. Some foods require heating to bring out their characteristic odours or flavours. Vegetable oils are often evaluated for odour after being equilibrated at 50 °C.

Panelists may prefer to evaluate some foods when they are served with carriers. Crackers, for instance, may be used as carriers for margarine or peanut butter. Use of carriers can present problems, however, because the carrier foods have flavour and texture characteristics of their own which can interfere with panelists' evaluation of the main food product.

The food samples being evaluated may be swallowed or expectorated, however, the panel should be encouraged to develop a consistent technique. Cups with lids should be provided for expectoration.

Room temperature water is often presented to panelists so that they can rinse their mouths before and between samples. Rinse water can be swallowed or expectorated. If room temperature water will not clear the mouth between tastings, warm water, lemon water, unsalted soda crackers, white bread or apple slices may be used. Warm water is particularly helpful when fats or oily foods are being tested. The time between evaluation of each sample may have to be longer than usual if the products being tested have strong flavours. It may also be necessary to restrict to two or three the number of samples presented at one session.

When characteristics other than colour are being evaluated it may be necessary to mask colour differences; otherwise they may influence the panelists' judgements of other characteristics. Red, blue, green or yellow light, whichever masks the sample differences most effectively, can be used.

4.4 USING REFERENCE SAMPLES

References are often used in sensory testing. These can be designated reference samples, against which all other samples are to be compared; or they can be identified samples used to mark the points on a measurement scale; or they can be hidden references, coded and served to panelists with the experimental samples in order to check panelist performance.

When sensory tests are conducted over several weeks or months, or when the testing must be done at widely spaced intervals as is the case when storage effects are being studied, then it is almost essential to use a designated reference. This can be selected from among the actual foods or samples that are to be tested, or can be a food product of a similiar type. When conducting a storage study the designated reference may be the control (a sample stored under standard conditions), or may be a fresh sample. If the purpose of the research is to produce a product that is an improvement on a marketed product, then the product being marketed can serve as the reference. When the testing is done by a trained panel, this panel should evaluate the reference before the actual testing is begun. Scores which this panel agrees are appropriate, for each characteristic to be measured, can then be placed on the ballot to be used during the experiment. Providing a scored, designated reference to the panelists at each panel session should help them score the experimental samples more consistently.

Reference samples which are used to mark points on a scale, or to calibrate the scale, are often called standards. These references may be of food similar to that being tested, or may be totally different. If a number of product characteristics are being evaluated, many references (standards) may be necessary. Examples of food references used to identify scale endpoints for cooked bean textural characteristics of hardness, particle size, and seedcoat toughness, are given in Appendix 5.

Hidden references, or blind controls as they are sometimes called, can be served to the panel at some or all of the panel sessions, to check on the panelists' performance. The hidden reference must be sufficiently similar to the samples being tested that it cannot be immediately identified as the control sample. It should be coded in the same way as the experimental samples, using a different code number each time it is presented to the panel. If one or several panelists' scores for the hidden reference vary unacceptably, these panelists should be given further training or their scores may have to be excluded from the dataset.

A reference will improve panel consistency only if the reference itself is consistent. If the reference changes, it will not serve its intended purpose. Ideally, enough of the product reference should be obtained initially to serve for the entire experiment, and the product should be stored so that its sensory qualities do not change over the testing period. If a "new" reference is introduced part way through a study, or if the quality of the reference changes, results of the experiment may be impossible to interpret. If the product reference is a food that must be freshly prepared for each panel session, then ingredients and methods of preparation should be well standardized before the experiment begins.

✦ *Chapter 5*

Reducing Panel Response Error

During sensory testing panelists' responses can be influenced by psychological factors. If the influence of psychological factors is not taken into account when an experiment is planned and conducted, the error introduced can lead to false results. Psychological factors can be responsible for a number of different types of error. Errors that result from panelists' expectations, from sample positions, and from stimulus and contrast effects will be discussed in the following sections.

5.1 EXPECTATION ERRORS

Expectation errors can occur when panelists are given too much information about the nature of the experiment or the types of samples before tests are conducted. If the panelists expect to find certain differences among the samples, they will try to find these differences. Panelists should be given only the information that they need to perform their task, and when the experiment is under way, they should be discouraged from discussing their judgements with each other. Those conducting the experiment or whose knowledge of it leads them to expect particular results, should not participate in the panel.

Panelists may have other expectations about the test samples. They may expect that a sample coded as A will be "better" than a sample coded as F or that a sample coded as 1 will have more of a characteristic than a sample coded as 5. To prevent these expectation errors, each sample should be coded with a 3-digit random number (such as 374 or 902). Three digit codes do not influence panelists' judgements as do single number or letter codes. Random number tables, such as the one shown in Appendix 7, Table 7.1, are useful in choosing random numbers. Starting anywhere on the table, beginning at a different place each time and moving in a different direction, you can choose 3-digit numbers down a column or across a row.

5.2 POSITIONAL ERRORS

The way samples are positioned or ordered for evaluation can also influence panelists' judgements. For example, when two samples are presented, the first sample evaluated is often preferred or given a higher score. Randomizing the order of sample presentation so that the samples are presented in different positions to each panelist can minimize positional errors.

5.3 STIMULUS ERRORS

Stimulus errors occur when panelists are influenced by irrelevant sample differences such as differences in the size, shape or colour of food samples presented. Greater colour intensity for example, may lead panelists to score a food higher for flavour intensity, even when these characteristics are unrelated to each other. To minimize stimulus errors, the samples presented should be as similar as possible in all characteristics but the one(s) being evaluated. Colour differences can be masked by using coloured lights in the panel booths, as mentioned earlier. Alternately, dark glasses or blindfolds may be used if appropriate. Evaluating each characteristic separately, for all samples, will also reduce the error due to association of characteristics. When evaluating the colour, texture and flavour of three pudding samples, the stimulus error is reduced if the colour of all three samples is evaluated, then the texture of all three samples, and finally the flavour of all three samples, rather than evaluating the colour, texture and flavour of the first sample, then the colour, texture and flavour of the second sample and then the colour, texture and flavour of the third sample.

5.4 CONTRAST ERRORS

Contrast effects between samples can also bias test results. Panelists who evaluate a sample that is very acceptable before a less acceptable sample may score the acceptability of the second sample lower than they would if a less acceptable sample had been evaluated before it. Similarly, evaluating an unacceptable sample directly before an acceptable sample may result in amplifying the acceptability score given to the acceptable sample. When panelists evaluate a mildly flavoured sample after one with an intense flavour, their response will be influenced by the contrast between the two samples. If all panelists receive samples in the same order, contrast effects can have a marked influence on panel data. Contrast effects cannot be eliminated during sensory testing, but if each panelist receives samples in a different order, contrast effects can be balanced for the panel as a whole. Samples can be presented randomly to each panelist or all possible orders of the sample set can be presented. For example, when four samples are presented to each panelist at one time, four samples can be arranged and presented in 24 combinations. To ensure that a panelist evaluates the samples in the order selected for him/her, code numbers should be written in the appropriate order on the ballot and the panelist instructed to evaluate samples in the order indicated on the ballot. If possible, the coded samples on the tray should also be arranged for presentation to each panelist in the appropriate order, so that the evaluation can be done from left to right.

◆ *Chapter 6*

Collecting And Analyzing Sensory Data

Sensory data can be in the form of frequencies, rankings, or quantitative numerical data. The form of the data depends on the type of measurement scale used for sensory testing. To analyze the data statistically, methods appropriate for frequency, ranked or quantitative data must be applied. Types of scales and the statistical methods appropriate for analysis of the data obtained will be described briefly in the following section.

6.1 MEASUREMENT SCALES

Measurement scales are used to quantify sensory information. Scales can be classified according to their type as nominal, ordinal, interval or ratio scales. Because the type of scale chosen will affect the type of statistical analysis done, the measurement scale should be chosen only after careful consideration of the objectives of the study.

6.1.1 Nominal Scales

Nominal scales are the simplest of all scales. In these types of scales, numbers represent labels or category names and have no real numerical value. For example, panelists can use a nominal scale to identify odour characteristics of tomato sauces where 1 = fruity, 2 = sweet, 3 = spicy, and 4 = pungent. Panelists record the number of each odour characteristic present in each of the samples and the panel leader tabulates the frequency of the appearance of each characteristic for each sample. The products are then compared by observing the frequency of each odour characteristic in each sample.

Names only, rather than numbers representing names, can be used in a nominal scale. Classifications or categories can be given names and the frequencies within each classification tabulated and compared. Food samples could be classified as acceptable or unacceptable and the number of panelists placing a sample in the unacceptable category compared to the number of panelists considering it acceptable.

6.1.2 Ordinal Scales

In ordinal scales the numbers represent ranks. Samples are ranked in order of magnitude. Ranks do not indicate the size of the difference between samples. Ranking is used for both consumer-oriented and product-oriented testing. In consumer panels, samples are ranked on the basis of preference or acceptability. Biscuits made from three different formulations could be ranked for preference with the sample ranked 1 as the most preferred and the sample ranked 3 as the least preferred. In product-oriented testing the intensities of a particular product characteristic are ranked. A series of five chicken soup samples could be ranked for saltiness, with the sample ranked 1 the most salty soup and the sample ranked 5 the least salty soup.

6.1.3 Interval Scales

Interval scales allow samples to be ordered according to the magnitude of a single product characteristic or according to acceptability or preference. The degree of difference between samples is indicated when interval scales are used. If chicken soups were evaluated using an interval scale, not only would the most salty sample be identified, but the number of intervals separating the most salty soup from the least salty soup would be known. To provide a measurement of the degree of difference between samples the length of the intervals on the scale must be equal.

Category scales and line scales (Figure 7) are two types of sensory scales, commonly treated as interval scales. A category scale is one that is divided into intervals or categories of equal size. The categories are labelled with descriptive terms and/or numbers. All the categories may be labelled or only a few, such as the endpoints and/or midpoint of the scale. The total number of categories used varies, however, 5-9 categories are common. Pictures or diagrams illustrating the categories on the scale are particularly useful if panelists have trouble reading or understanding the language of the scale (Figure 7). Line scales, with endpoints and/or midpoint of the scale labelled, are commonly used to quantify characteristics. The length of the line scale can vary, but 15 cm is often used. Panelists may not always use category and line scales as equal interval scales. This is particularly

a) 5-Point Category Scale for the Intensity of a Characteristic

CODE

__________ trace

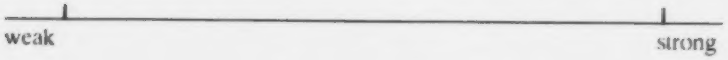
__________ slightly intense

__________ moderately intense

__________ very intense

__________ extremely intense

b) Line Scale for the Intensity of a Characteristic


weak
strong

c) Smiley Scale for Degree of Liking

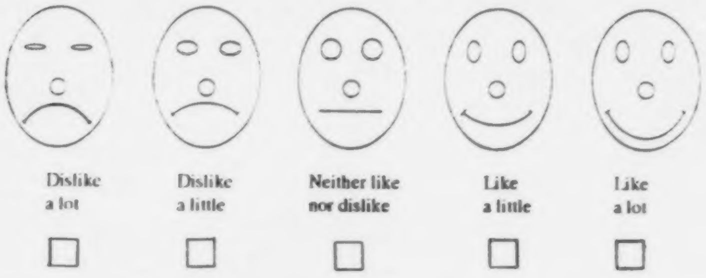

Dislike a lot ☐
Dislike a little ☐
Neither like nor dislike ☐
Like a little ☐
Like a lot ☐

Figure 7

Examples of Commonly Used Sensory Scales true of untrained consumer panelists. When in doubt about the equality of scale intervals, the panelists' scores should be converted to ranks and the category or line scales treated as ordinal scales. Examples in this manual will, however, be based on the assumption that equal interval sizes do exist between categories and along the line scales, and both scales will be considered and analyzed as interval scales.

Interval scales are used in both consumer-oriented and product-oriented tests. The degree of liking, the level of preference or the acceptability of the products are scored in consumer tests. The intensity of product attributes are scored in product-oriented testing.

6.1.4 Ratio Scales

Ratio scales are similar to interval scales, except that a true zero exists. On an interval scale the zero end point is chosen arbitrarily and does not necessarily indicate the absence of the characteristic being measured. On a ratio scale the zero point indicates the complete absence of the characteristic. If a ratio scale were used to measure the five chicken soup samples, the number of saltiness intervals separating the samples would indicate how many times more salty one sample was than another. If two of the samples, A and B, were given scores of 3 and 6 respectively for salty flavour intensity, on a ratio scale, sample B would be twice as salty as sample A. Ratio scales are seldom used for consumer-oriented testing, because training is required to use ratios successfully.

6.2 STATISTICAL ANALYSIS

Sensory results are analyzed statistically in order to allow the experimenter to make inferences or draw conclusions about populations of people or food products on the basis of a sample drawn from these populations. Prior to conducting the experiment, assumptions or informed guesses, can be made about the populations and about the expected results of the experiment. These assumptions are called hypotheses, and can be stated in two ways. The assumption that no difference exists between two samples, or among several samples, is termed the null hypothesis. This is also the statistical hypothesis which, based on statistical analysis of experimental results, is accepted or rejected. The other assumption that can be made is that differences do exist between or among samples. This is the alternate hypothesis, or what is often termed the research hypothesis. For example, in an experiment to determine whether adding salt to cooking water produces softer beans, the null hypothesis would be that there is no difference in softness between beans cooked with or without added salt. The alternate (or research) hypothesis might state that the beans cooked with salt are softer than those without salt. Using the appropriate statistical test, it is possible to determine whether the null hypothesis should be accepted or rejected. If it is accepted, then the conclusion is that there is no difference in softness between beans cooked by the two methods according to this test. If it is rejected, then the conclusion is that the beans cooked with salt are probably softer.

Results of statistical tests are expressed by giving the probablity that the outcome could be due to a chance occurrence rather than being a real difference. If a result occurs 5 times out of 100, due to chance, then the probability is said to be 0.05. A statistical result is usually considered significant only if its probability is 0.05 or less.

At this level of probability, the null hypothesis will be rejected 5 times out of 100 when in fact it should be accepted. When it is stated that a difference is significant at the 5 percent level (a probability of 0.05), it means that 95 times out of 100 the difference is a real one.

The level of significance to be used in a sensory test should be decided on before the test is carried out. This is done so that the results of the test do not influence the decision. Usually levels of 0.05 or 0.01 are employed. Using a level of significance of 0.05 rather than 0.01 makes it more likely that a difference will be found if one exists (*i.e.* the null hypothesis is more likely to be rejected). However, it also means that there is a greater probability that the difference identified is due to chance.

In consumer-oriented testing inferences can be made concerning a group, such as the intended users of a food product, if the group or population has been sampled randomly to form the consumer panel. In product-oriented testing, panelists are not selected randomly and no inferences can be made about a particular population of consumers. Inferences can be made, however, about the characteristics of the population of foods being tested. In both types of testing the food samples should be chosen at random from the product lots of interest, if results are to be inferred for the product as a whole. When sampling cannot be done on a random basis, care must be taken in generalizing the conclusion of the test to the wider group or population.

Random sampling of a population requires that every unit of the population has an equal chance of being selected. Obtaining a truly random sample of a food product is seldom possible. However, it is important that the samples to be tested are as representative of the original batch of food as possible.

A sample lot large enough to provide for all components of the study should be gathered initially. Subsamples from this lot should be assigned randomly to each experimental treatment or replication or block. At each stage of the process, subsamples or portions are randomly chosen.

6.3 STATISTICAL TESTS

Statistical tests are used to analyze data resulting from sensory studies. Statistical analyses are used for the following purposes:

1) to test hypotheses.

2) to find out if significant differences exist among samples, treatments or populations and if these differences are conditional upon other variables or parameters.

3) to monitor the consistency of trained panelists both during training and during the actual study.

6.3.1 Statistical Tests for Scalar Data

Data from nominal and ordinal scales are analyzed using non-parametric statistical tests while data from interval and ratio scales are analyzed using parametric statistical tests. Non-parametric methods are less discriminating than parametric tests but do not require data to be normally and independently distributed as do parametric tests. Parametric tests also require interval scales to have intervals or categories that are equal both psychologically and in size. If this is not true, then the categories should be treated as nominal data and analyzed by non-parametric methods. The use of parametric tests versus non-parametric tests for the analysis of category scale data has been discussed in numerous books and articles (O'Mahony, 1986, 1982; McPherson and Randall, 1985; Powers, 1984; Gacula and Singh, 1984; Daget, 1977).

Nominal sensory data is usually analyzed by binomial or chi-square tests. Ordinal or ranked sensory data is most frequently analyzed by the Kramer test or the Friedman test. The Kramer test, however, has recently been found to be inappropriate (Basker, 1988; Joanes, 1985) and is not recommended. The most common parametric test for interval or ratio scale sensory data is the Analysis of Variance (ANOVA).

Multiple comparison of means tests are utilized to identify samples that differ from each other, once the presence of statistical differences has been confirmed using Analysis of Variance. Many multiple comparison tests, such as Duncan's New Multiple Range Test, Tukey's Test, the Least Significant Difference (LSD) Test and Scheffe's Test, are available. Of these, the LSD test is the most powerful and most liberal test, followed by Duncan's, Tukey's and Scheffe's test. Thus, using the LSD test will make it more likely to find significant differences between two samples. However, it may also identify differences when none really exist. Scheffe's test, on the other hand, is very cautious or conservative and may miss finding differences when they do exist. Duncan's and Tukey's test are frequently used for sensory data as they are considered neither too liberal nor too conservative.

Multivariate analysis techniques can be used when relationships among a number of different measurements or tests are being investigated. Correlation and Regression Analysis, Discriminant Analysis, Factor Analysis and Principal Component Analysis are types of multivariate analysis frequently used in sensory studies. These analyses require sophisticated statistical treatment, and will not be discussed in this manual. For further information on the use of multivariate techniques for sensory analysis data see O'Mahony (1986), Gacula and Singh (1984), Piggott (1984), Powers (1984, 1981), Moskowitz (1983), Ennis *et al.* (1982) and Stungis (1976).

Programmable calculators can be used to analyze small data sets using the statistical tests illustrated in this manual. Computerized statistical programs or packages are needed to carry out more complicated statistical analyses.

6.4 EXPERIMENTAL DESIGN

Experimental designs are plans, arrangements, or a sequence of steps for setting up, carrying out and analyzing the results of an experiment. An appropriate and efficient experimental design must be chosen to ensure the reliability of data and test results. The design is selected based on the objectives of the study, the type of product under study, the testing procedures and conditions, the resources available and the type of statistical test to be conducted.

There are many types of experimental designs from simple, completely randomized designs to more complicated, fractional factorial designs. Good statistical textbooks and a statistician should be consulted to recommend the simplest, most efficient design to meet the specific objectives of the study.

Common features of good experimental designs are randomization, blocking and replication. These concepts are discussed in the following sections.

6.4.1 Randomization

Randomization is introduced into an experimental design to minimize the effects of uncontrollable sources of variation or error and to eliminate bias. Randomization is a procedure for ordering units or samples such that each unit has an equal chance of being chosen at each stage of the ordering process. For example, to randomize the assignment of different cooking treatments to food samples, one sample is chosen to be cooked by method 1, but all of the other samples have an equal chance of being cooked by that same method. Random number tables (Appendix 7, Table 7.1) are used for randomization in the same manner as was described for choosing 3-digit random numbers (Section 5.1).

6.4.2 Blocking

Blocking is included in many experimental designs to control for known sources of variation and to improve efficiency. Blocks may be growing plots, day effects, panelists, replications or sample presentation orders; anything that is a known source of error in the experiment. Experimental units are grouped into blocks. Variation among the units within a block is likely to be less than the variation among blocks. Blocking provides a truer measure of pure or experimental error by accounting for the variance due to the blocked factors and separating it out from the uncontrollable sources of experimental error. For instance, sensory panelists, being human, are often a known source of variability in sensory experiments. By blocking panelists in the experimental design and data analysis, the variation due to panelists can be removed from the experimental error and separated out as a panelist effect. Then the error term used to determine whether there are significant differences among the samples, will be more indicative of pure error.

6.4.3 Replication

Replication of an experiment involves repeating the entire experiment under identical conditions. Replication provides an estimate of experimental error and improves the reliability and validity of the test results. Through replication, the consistency of both the panel and individual panelists can be determined. The number of replications of an experiment varies and often is determined by considering time, cost and sample restraints, however, usually the more replications that are done, the better the estimate of experimental error and the more reliable the test results.

◆ *Chapter 7*

Sensory Tests: Descriptions and Applications

Sensory tests can be described or classified in several ways. Statisticians classify tests as parametric or non-parametric according to the type of data obtained from the test. Sensory specialists and food scientists classify tests as consumer-oriented (affective) or product-oriented (analytical), basing this classification on the purpose of the test. Tests used to evaluate the preference for, acceptance of, or degree of liking for food products are termed consumer-oriented. Tests used to determine differences among products or to measure sensory characteristics are termed product-oriented.

7.1 CONSUMER-ORIENTED TESTS

Preference, acceptance and hedonic (degree of liking) tests are consumer-oriented tests. These tests are considered to be consumer tests since they should be conducted using untrained consumer panels. Although panelists can be asked to indicate their degree of liking, preference or acceptance of a product directly, hedonic tests are often used to measure preference or acceptance indirectly. In this section preference, acceptance and hedonic tests will be described using a paired-preference test, an acceptance ranking scale, and a 9-point hedonic scale as examples.

7.1.1 Preference Tests

Preference tests allow consumers to express a choice between samples; one sample is preferred and chosen over another or there is no preference. The paired-preference test is the simplest preference test but category scales and ranking tests are also often used to determine preference.

General Instructions for Conducting a Paired-Preference Test.

Description of panelists' task: Panelists are asked which of two coded samples they prefer. Panelists are instructed to choose one, even if both samples seem equal. The option of including a "no preference" choice or a "dislike both equally" is discussed in Stone and Sidel (1985), but is not recommended for panels with less than 50 panelists as it reduces the statistical power of the test (a larger difference in preference is needed in order to obtain statistical significance).

Presentation of samples: The two samples (A and B) are presented in identical sample containers coded with 3-digit random numbers. There are two possible orders of presentation of the samples; A first, then B (AB) or B first, then A (BA). Each order should be presented an equal number of times. If the panel included 20 panelists, ten would receive A first and ten, B first. When the panel is large, the order for each panelist can be selected at random. Since there is a 50% chance of each panelist receiving either the A or B sample first, both orders should be presented to approximately the same number of panelists.

The samples are presented simultaneously in the order selected for each panelist, so that the panelists can evaluate the samples from left to right. Retasting of the samples is allowed. An example of a ballot for the paired-preference test is given in Figure 8. The order in which the panelists are to evaluate the samples should be indicated on the ballot.

Analysis of data: Results are analyzed using a 2-tailed binomial test. The 2-tailed test is appropriate since either sample could be preferred; and the direction of the preference cannot be determined in advance. The number of judges preferring each sample is totalled and the totals tested for significance using Table 7.2 (Appendix 7). In this table X represents the number of panelists preferring a sample and n represents the total number of panelists participating in the test. The table contains 3 decimal probabilities for certain combinations of X and n. In the table, the decimal point has been omitted to save space, therefore 625 should be read as 0.625. For example, if 17 out of 25 panelists prefer sample A, the probability from Table 7.2 ($X = 17$, $n = 25$) would be 0.108. Since a probability of 0.05 or less is usually required for the result to be considered significant, it would be concluded that sample A was not significantly preferred over sample B. Had 19 of the 25 judges chosen sample A as being the preferred sample, the probability would have been 0.015 and a significant preference for sample A would have been shown.

No knowledge of the degree of preference for the preferred sample or of the degree of difference in preference between the samples results from the paired-preference test.

Example of a paired-preference test used by an in-house consumer panel to determine preference for pureed beans

Bean purees were prepared from two varieties of black beans, A (631) and B(228). A paired-preference test was used to determine if one bean puree was preferred over the other.

Forty untrained panelists were recruited from within the institute (in-house panel). The two samples were presented to each panelist simultaneously. Each panelist evaluated the two samples only once. Twenty panelists received sample A (631) first, twenty panelists received sample B (228) first. The ballot used when sample A was presented first is shown in Figure 8.

The number of panelists who preferred each sample was totalled. Thirty of the forty panelists preferred sample B. In Table 7.2 (Appendix 7) for $X = 30$ and $n = 40$, the probability is 0.002. This result was therefore statistically significant, and it was concluded that the in-house panel preferred bean puree B over bean puree A.

Name: ____________________________

Date: ______________________________

Taste the two bean puree samples in front of you, starting with the sample on the left. Circle the number of the sample that you prefer. You must choose a sample. Guess if you are unsure.

631 228

Figure 8 Ballot for bean puree paired-preference test

7.1.2 Acceptance Tests

Acceptance tests are used to determine the degree of consumer acceptance for a product. Category scales, ranking tests and the paired-comparison test can all be used to assess product acceptance. Acceptance of a food product usually indicates actual use of the product (purchase and eating).

General Instructions for Conducting an Acceptance Test Using Ranking.

Description of panelists' task: Panelists are asked to rank coded samples for acceptance in order from the least acceptable to the most acceptable. Ties, where the samples are given equal acceptance ranks, are not usually allowed.

Presentation of samples: Three or more samples are presented in identical sample containers, coded with 3-digit random numbers. Each sample is given a different number. All the samples are simultaneously presented to each panelist in a balanced or random order and retasting of the samples is allowed. An example of a ballot for ranking of acceptance is given in Figure 9.

Name: ____________________

Date: ____________________

Please taste each of the samples of black beans in the order listed below. Assign the sample with the most acceptable texture a rank value of 1, the sample with the next most acceptable texture a rank value of 2, and the sample with the least acceptable texture a rank value of 3. Do not give the same rank to two samples.

Code	**Rank assigned**
________	________
________	________
________	________

Figure 9 Ballot for bean texture acceptability ranking test

Analysis of data: For data analysis, the ranks assigned to each sample are totalled. The samples are then tested for significant differences by comparing the rank totals between all possible pairs of samples using the Friedman Test. Tables 7.3 and 7.4 (Appendix 7) present expanded tables for this test, for 3-100 panelists and 3-12 samples (Newell and MacFarlane, 1987). The differences between all possible rank total pairs are compared to the tabulated critical value, based on a specific significance level (5% in Table 7.3; 1% in Table 7.4) and the number of panelists and samples involved in the test. If the difference beween pairs of rank totals is larger than the tabulated critical value, the pair of samples are significantly different at the chosen significance level.

Example of a ranking test used by an in-house consumer panel to determine acceptability of bean texture.

Cooked bean samples were prepared from three varieties of black beans. A ranking test was used to obtain an indication of the most acceptable black bean texture.

Thirty untrained panelists were recruited from within the institution (in-house panel). All treatments were simultaneously presented to each panelist. Each panelist evaluated the samples only once. The three samples could be served in six possible orders, as shown in Table 4 (Section 7.2.1). Since there were thirty panelists, the order of sample presentation was balanced such that five panelists received samples in each of the six possible orders. The ballot used for ranking acceptability is shown in Figure 9. Panelists were instructed to rank the texture of the samples for acceptability without ties, giving each sample a different rank even if they seemed to be similar. The sample which was ranked as having the most acceptable texture was assigned a rank of 1, the sample with the next most acceptable texture was assigned a rank of 2 and the sample with the least acceptable texture was assigned a rank of 3. The ranked values given to each sample by all 30 panelists were tabulated as shown in Table 1.

The differences between rank total pairs were:

C - A = 76-33 = 43

C - B = 76-71 = 5

B - A = 71-33 = 38

The tabulated critical value at p=0.05, for 30 panelists and three samples, from Table 7.3, is 19. Thus, the cooked texture of bean varieties A and C were significantly different and the cooked texture of bean varieties A and B were significantly different.

The in-house panel found the cooked texture of black bean varieties B and C less acceptable than the cooked texture of bean variety A. There was no difference in texture acceptability between varieties B and C.

7.1.3 Hedonic Tests

Hedonic tests are designed to measure degree of liking for a product. Category scales ranging from like extremely, through neither like nor dislike, to dislike extremely, with varying numbers of categories, are used. Panelists indicate their degree of liking for each sample by choosing the appropriate category.

Table 1
Tabulated Ranking[1] for Acceptance Test Data

Panelist	Black Bean Varieties		
	A	B	C
1	1	2	3
2	1	3	2
3	1	2	3
4	1	2	3
5	1	3	2
6	1	2	3
7	1	2	3
8	1	3	2
9	1	2	3
10	2	1	3
11	1	3	2
12	1	3	2
13	1	3	2
14	1	2	3
15	1	3	2
16	1	2	3
17	1	3	2
18	1	2	3
19	1	2	3
20	1	3	2
21	1	3	2
22	1	2	3
23	1	2	3
24	1	3	2
25	1	3	2
26	2	1	3
27	1	2	3
28	1	3	2
29	1	3	2
30	2	1	3
Rank Total	33	71	76

[1] Highest rank = 1 = most acceptable texture, 3 = least acceptable texture

General Instructions for Conducting a Hedonic Test Using a 9-point Scale.

Description of panelists' task: Panelists are asked to evaluate coded samples of several products for degree of liking, on a 9-point scale. They do this by checking a category on the scale which ranges from like extremely to dislike extremely. More than one sample may fall within the same category.

Presentation of samples: The samples are presented in identical sample containers, coded with 3-digit random numbers. Each sample must have a different number. The sample order can be randomized for each panelist or, if possible, balanced. In a balanced serving order each sample is served in each position (*i.e.* first, second, third, *etc.*) an equal number of times. A good discussion of serving orders with examples of 3, 4, 5 and 12 sample balanced designs is given in Stone and Sidel (1985). A balanced serving order for three samples is given in Table 4 (Section 7.2.1). Samples may be presented all at once or one at a time. Presenting the samples simultaneously is preferred as it is easier to administer and allows panelists to re-evaluate the samples if desired and make comparisons between the samples. An example of a ballot for the hedonic test is given in Figure 10.

Analysis of Data: For data analysis, the categories are converted to numerical scores ranging from 1 to 9, where 1 represents dislike extremely and 9 represents like extremely. The numerical scores for each sample are tabulated and analyzed by analysis of variance (ANOVA) to determine whether significant differences in mean degree of liking scores exist among the samples. In the ANOVA, total variance is partitioned into variance assigned to particular sources. The among-sample means variance is compared to the within-sample variance (also called the random experimental error)[1]. If the samples are not different, the among-sample means variance will be similiar to the experimental error. The variance due to panelists or other blocking effects can also be tested against the random experimental error.

The measure of the total variance for the test is the total sum of squares or *SS*(T). The measured variance among the sample means is the treatment sum of squares or *SS*(Tr). The measure of the variance among panelists' means is the panelist sum of squares or *SS*(P). Error sum of square, *SS*(E), is the measure of the variance due to experimental or random error. Mean Squares (*MS*) for treatment, panelist and error are calculated by dividing each *SS* by its respective degrees of freedom. The ratios of the *MS*(Tr) to the *MS*(E) and the ratio of the *MS*(P) to the *MS*(E) are then calculated. These ratios are termed F ratios or F statistics. Calculated F ratios are compared to tabulated F ratios (Tables 7.5 and 7.6, Appendix 7) to determine whether there are any significant differences among the treament or panelists' means. If the calculated F ratio exceeds the tabulated F ratio for the same number of degrees of freedom, then there is evidence of significant differences. Tabulated F ratios are given for 0.05 and 0.01 levels of significance in Tables 7.5 and 7.6, respectively.

Once a significant difference has been found, multiple comparison tests can be carried out to determine which treatment or population means differs from each other. Details of the ANOVA calculations are given in the following example.

---

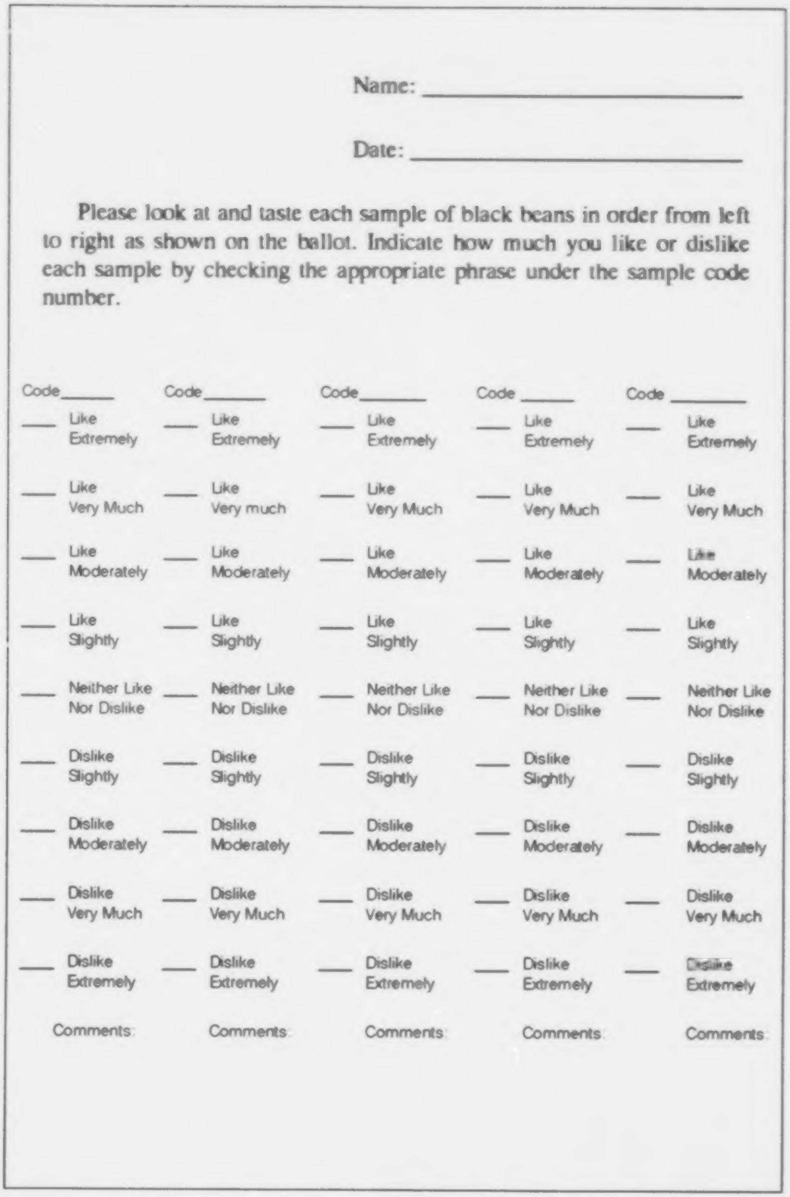
[1] Since the total variance within-samples comes from pooling individual variances within-samples, a necessary assumption is that the true within-sample variances are equal. There are formal tests that can be done to test for equality of within-sample variances (Homogeneity of Variance).

Example of a hedonic test used by an in-house consumer panel to determine degree of liking for bean varieties.

A hedonic test was conducted to determine consumers' degree of liking for five varieties (treatments) of cooked black beans using the 9-point category scale shown in Figure 10.

The beans were cooked, staggering the cooking times, so that all five samples were done ten minutes before the panel began. Twenty-eight untrained in-house consumer panelists evaluated the five samples once. Ten gram samples of the five varieties of beans were presented simultaneously, in styrofoam sample cups with lids, to each panelist. For five samples, 120 serving orders were possible, however, with only 28 panelists this large number of serving orders was impossible to balance. Therefore, the serving order was randomized for each panelist.

After each panelist had evaluated the five samples, the descriptive categories were converted to numerical scores. The scores were tabulated and analyzed by analysis of variance. The tabulated scores for the first seven panelists are shown in Table 2. The analysis of variance shown was carried out using the scores for the seven panelists only.



Name: ______________________

Date: ______________________

Please look at and taste each sample of black beans in order from left to right as shown on the ballot. Indicate how much you like or dislike each sample by checking the appropriate phrase under the sample code number.

Code_____	Code______	Code_______	Code _____	Code _______
___ Like Extremely	___ Like Extremely	___ Like Extremely	___ Like Extremely	___ Like Extremely
___ Like Very Much	___ Like Very much	___ Like Very Much	___ Like Very Much	___ Like Very Much
___ Like Moderately	___ Like Moderately	___ Like Moderately	___ Like Moderately	___ Like Moderately
___ Like Slightly	___ Like Slightly	___ Like Slightly	___ Like Slightly	___ Like Slightly
___ Neither Like Nor Dislike	___ Neither Like Nor Dislike	___ Neither Like Nor Dislike	___ Neither Like Nor Dislike	___ Neither Like Nor Dislike
___ Dislike Slightly	___ Dislike Slightly	___ Dislike Slightly	___ Dislike Slightly	___ Dislike Slightly
___ Dislike Moderately	___ Dislike Moderately	___ Dislike Moderately	___ Dislike Moderately	___ Dislike Moderately
___ Dislike Very Much	___ Dislike Very Much	___ Dislike Very Much	___ Dislike Very Much	___ Dislike Very Much
___ Dislike Extremely	___ Dislike Extremely	___ Dislike Extremely	___ Dislike Extremely	___ Dislike Extremely
Comments:	Comments:	Comments:	Comments:	Comments:

Figure 10 Ballot for bean varieties hedonic test using a 9-point scale

For the analysis of variance (ANOVA), the following calculations were carried out, (where N = the total number of individual responses, Σ = sum of):

Correction Factor:

$$CF = \frac{\text{Grand Total}^2}{N}$$

$$= \frac{163^2}{35}$$

$$= 759.1$$

Total Sum of Squares:

$$SS(T) = \Sigma(\text{each individual response}^2) - CF$$

$$= (2^2 + 1^2 + 1^2 + \ldots + 2^2 + 3^2) - 759.1$$

$$= 917 - 759.1$$

$$= 157.9$$

Treatment Sum of Squares:

$$SS\ (Tr) = \frac{\Sigma(\text{each treatment total}^2)}{\text{number of responses per treatment}} - CF$$

$$= \frac{15^2 + 43^2 + 52^2 + 31^2 + 22^2}{7} - 759.1$$

$$= \frac{6223}{7} - 759.1$$

$$= 889 - 759.1$$

$$= 129.9$$

Panelist Sum of Squares:

$$SS(P) = \frac{\Sigma\,(\text{each panelist total}^2)}{\text{number of responses per panelist}} - CF$$

$$= \frac{26^2 + 25^2 + 18^2 + 23^2 + 23^2 + 24^2 + 24^2}{5} - 759.1$$

$$= \frac{3835}{5} - 759.1 = 767 - 759.1$$

$$= 7.9$$

Error Sum of Squares:

$$SS(E) = SS(T) - SS(Tr) - SS(P)$$

$$= 157.9 - 129.9 - 7.9$$

$$= 20.1$$

Table 2
Tabulated Category Scores[1] for the Hedonic Test

	Black Bean Varieties (Treatments)						
Panelist[2]	A	B	C	D	E	Panelist Total	Panelist Mean
1	2	6	8	6	4	26	5.2
2	1	7	9	4	4	25	5.0
3	1	6	6	3	2	18	3.6
4	2	6	6	5	4	23	4.6
5	2	6	8	4	3	23	4.6
6	4	7	7	4	2	24	4.8
7	3	5	8	5	3	24	4.8
TREATMENT TOTAL	15	43	52	31	22		
			GRAND TOTAL			163	
TREATMENT MEAN	2.1	6.1	7.4	4.4	3.1		

[1] Highest score = 9 = like extremely Lowest score = 1 = dislike extremely

[2] the responses of only 7 of the 28 panelists are given and analyzed

The mean square (*MS*) values were calculated by dividing the *SS* values by their respective degrees of freedom as follows:

Total Degrees of Freedom, df(T) = The total number of responses - 1
= N - 1
= 35 - 1
= 34

Treatment Degrees of Freedom, df(Tr) = The number of treatments - 1
= 5 - 1
= 4

Panelist Degrees of Freedom, df(P) = The number of panelists - 1
= 7 - 1
= 6

Error Degrees of Freedom, df(E) = df(T) - df(Tr) - df(P)
= 34 - 4 - 6
= 24

Treatment Mean Square, *MS*(Tr) = *SS*(Tr) / df(Tr)

$$= \frac{129.9}{4} = 32.48$$

Panelist Mean Square, *MS*(P) = *SS*(P) / df(P)

$$= \frac{7.9}{6} = 1.32$$

Error Mean Square, *MS*(E) = *SS*(E) / df(E)

$$= \frac{20.1}{24} = 0.84$$

The F ratios, for treatments and panelists were calculated by dividing their respective *MS* values by the *MS* for error. The tabular F ratios were obtained from statistical tables of the F distribution (Appendix 7, Table 7.5). For example, the tabulated F ratio for treatments with 4 degrees of freedom (df) in the numerator and 24 df in the denominator, at $p \leq .05$, is 2.78. The F ratio for panelists with 6 df in the numerator and 24 df in the denominator at $p \leq .05$ is 2.51. The calculated F ratios must exceed these tabular F values in order to be considered significant at the 5% level.

The sums of squares, mean squares, degrees of freedom and F ratios are summarized in the ANOVA table shown in Table 3.

Table 3
ANOVA Table for the Hedonic Test

Source of Variation	df	SS	MS	F ratio Calculated	F ratio Tabular ($p \leq .05$)
Total (T)	34	157.9			
Treatment (Tr)	4	129.9	32.48	38.67	2.78
Panelists (P)	6	7.9	1.32	1.57	2.51
Error (E)	24	20.1	0.84		

Since the calculated treatment F ratio of 38.67 exceeded the tabulated F ratio of 2.78, it was concluded that there was a significant ($p \leq .05$) difference among the mean hedonic scores for the five bean varieties. The calculated panelist F ratio of 1.57, however, did not exceed the tabular F ratio of 2.51. Thus, no significant panelist effect was present.

The ANOVA indicated that there were significant differences among the five bean varieties. To determine which bean samples differed significantly from each other, a multiple comparison test, Duncan's New Multiple Range Test and Tables 7.7 and 7.8, Appendix 7, were used. This test compares the differences between all pairs of means to calculated range values for each pair. If the difference between pairs of means is larger than the calculated range value, the means are significantly different at the specified level of significance. Range values are computed based on the number of means that lie between the two means being tested, when the means are arranged in order of size.

To carry out the Duncan's Test, treatment means were arranged in order of magnitude as shown.

Black Bean Varieties	C	B	D	E	A
Treatment Means	7.4	6.1	4.4	3.1	2.1

To compare the 5 means in this example, range values for a range of 5, 4, 3 and 2 means were calculated from the following equation:

$$\text{Range} = Q\sqrt{\frac{MS(\text{E})}{t}}$$

The *MS*(E), taken from the ANOVA table (Table 3) was 0.84. The t is the number of individual responses used to calculate each mean; in this example t = 7.

$$\text{Range} = Q\sqrt{\frac{0.84}{7}} = Q\,(0.346)$$

Q values were obtained from Table 7.7 (Appendix 7) at the same level of significance used in the ANOVA, $p \leq .05$. The df(E), or 24 df, are also needed to determine Q values. From Table 7.7, Q values for 24 df are:

Q value for 5 means = 3.226
Q value for 4 means = 3.160
Q value for 3 means = 3.066
Q value for 2 means = 2.919

Range values were then calculated.

Range = Q (0.346)

Range for 5 means = 3.226 (0.346) = 1.12
Range for 4 means = 3.160 (0.346) = 1.09
Range for 3 means = 3.066 (0.346) = 1.06
Range for 2 means = 2.919 (0.346) = 1.01

The 5 mean range value was applied to the means with the greatest difference between them, 7.4 and 2.1, since these values covered the range over 5 means. The difference, 5.3, was greater than 1.12. These two means, therefore, were significantly different.

The next comparison was between the means 7.4 and 3.1, using the 4 mean range value (1.09). Since the difference between the means (4.3) was greater than 1.09, these means were also significantly different.

The three mean comparison was between means 7.4 and 4.4.

7.4 - 4.4 = 3.0 > 1.06

One two mean comparison was between 7.4 and 6.1.

7.4 - 6.1 = 1.3 > 1.01

The next highest mean was then compared with the lowest mean and the difference was compared to the range value for 4 means.

6.1 - 2.1 = 4.0 > 1.09

This procedure was carried out as shown, until all mean comparisons had been made.

6.1 - 3.1 = 3.0 > 1.06
6.1 - 4.4 = 1.7 > 1.01
4.4 - 2.1 = 2.3 > 1.06
4.4 - 3.1 = 1.3 > 1.01
3.1 - 2.1 = 1.0 < 1.01

The significant differences among the means were presented by using letters. Means followed by different letters were significantly different at the 5% level of probability.

Black Bean Varieties	C	B	D	E	A
Treatment Means	7.4a	6.1b	4.4c	3.1d	2.1d

Bean variety C was liked significantly more than all other samples; variety B was significantly more liked than varieties D, E and A; variety D was liked more than varieties E and A; variety E and A were equally liked.

7.2 PRODUCT-ORIENTED TESTS

Product-oriented tests commonly used in food testing laboratories include difference, ranking for intensity, scoring for intensity, and descriptive analysis tests. These tests are always conducted using trained laboratory panels. Examples of product-oriented tests which have been included in this manual are: a triangle test for difference, a ranking test for intensity and a scoring test for intensity.

7.2.1 Difference Tests

Tests for difference are designed to determine whether two samples can be distinguished from each other by sensory analysis. Difference tests can be used to determine whether a noticeable change has occurred in a food's appearance, flavour, or texture as a result of storage, of a change in processing methods, or of alteration of an ingredient.

The triangle test is a form of difference test that is commonly used to determine whether there are perceptible differences between two samples. The size and direction of difference between two samples, however, is not specified in this test. The test may also be used to determine panelists' ability to discriminate differences in appearance, odour, flavour or texture of foods. To test for discrimination of differences related to one characteristic, the samples being compared must be identical in all other characteristics. Other tests, such as the paired-comparison or duo-trio test can be used for similar purposes.

The paired-comparison test is similar to the paired-preference test described in Section 7.1.1, except that panelists are asked which of the two samples has the greater intensity of a specific characteristic. For example, panelists may be asked "which sample is sweeter?" or "which sample is most tender?". Using this test the sweeter or more tender sample can be identified, but the extent of the difference is not measured.

In the duo-trio test panelists are presented with three samples. One sample is labelled R for reference and the other two samples are coded with 3-digit random numbers. One of the coded samples is identical to the reference (R) and the other is not. Panelists are asked to taste R first, then the coded samples and identify which of the two coded samples is the same as R (or different from R). The duo-trio test indicates difference, but not the direction or magnitude of the difference between samples.

The paired-comparison and duo-trio difference tests will not be described in detail in this manual. Procedures for conducting these tests and analyzing the data are described by O'Mahony (1986), Stone and Sidel (1985), Gacula and Singh (1984), Larmond (1977) and ASTM Committee E-18 (1968).

General Instructions for Identifying a Difference Using a Triangle Test

Description of panelists' task: Panelists are presented with three coded samples, one different and two the same, and asked to select the different sample. Panelists are required to select the different sample even if they cannot discern any differences among the samples (*i.e.* panelists must guess when in doubt).

Presentation of samples: The two different samples (A and B) are presented to the panelists in sets of three. Panelists receive either two A's and one B, or two B's and one A. The three samples are presented in identical sample containers coded with 3-digit random numbers. All three code numbers on the samples presented to each panelist must be different, even though two of the samples are identical.

There are six possible serving orders for the triangle test and these are shown in Table 4. Each order should be presented an equal number of times, for a balanced serving order. This is possible, however, only if there are six, or some multiple of six, panelists. Alternately the order can be randomized so that each panelist has an equal chance of receiving any of the six possible serving orders.

The samples are presented simultaneously in the order selected for each panelist so that the panelists can evaluate the samples from left to right. Retasting of the samples is allowed. An example of a ballot for the triangle test is given in Figure 11. The order in which the panelists are to evaluate the samples should be indicated on the ballot.

Table 4
Six Possible Serving Orders for a Triangle Test

Panelist Number	Order of Sample Presentation		
	First	Second	Third
1	256(A)	831(A)	349(B)
2	256(A)	349(B)	831(A)
3	670(B)	256(A)	831(A)
4	349(B)	670(B)	256(A)
5	349(B)	256(A)	670(B)
6	831(A)	349(B)	670(B)

Analysis of Data: Results are analyzed using a one-tailed binomial test for significance. The one-tailed test is appropriate since one sample is known to be different and there is therefore only one "correct" answer. The 2-tailed binomial test was used to analyze the paired-preference data of Section 7.1.1. For that test either of the two samples could have been preferred; that is, two "correct" answers were possible, and so a 2-tailed test of significance was used. The triangle test also differs from the paired test in that the probability of picking the correct sample by chance is 1/3. In the paired test the probability of picking the correct sample by chance is 1/2. Thus the table used for the triangle test (Table 7.9) is not the same as the one used for the paired test (Table 7.2).

In the triangle test the number of panelists correctly identifying the different sample is totalled and the total tested for significance using Table 7.9 (Appendix 7). In this table *X* represents the number of panelists choosing the different sample correctly and *n* represents the total number of panelists participating in the test. The table contains 3 decimal probabilities for certain combinations of *X* and *n*. In Table 7.9 the initial decimal point has been omitted to save space, therefore 868 should be read as 0.868. For example, if 9 out of 17 panelists correctly choose the different sample, the probability from Table 7.9 (X=9, n=17) would be 0.075. Since a probability of 0.05 or less is usually required for significance, it would be concluded that there was no significant difference between the samples. In this type of difference test, both reliability and sensitivity improve when more panelists are used.

Example of a triangle test used by a trained panel to detect difference between treated and untreated samples.

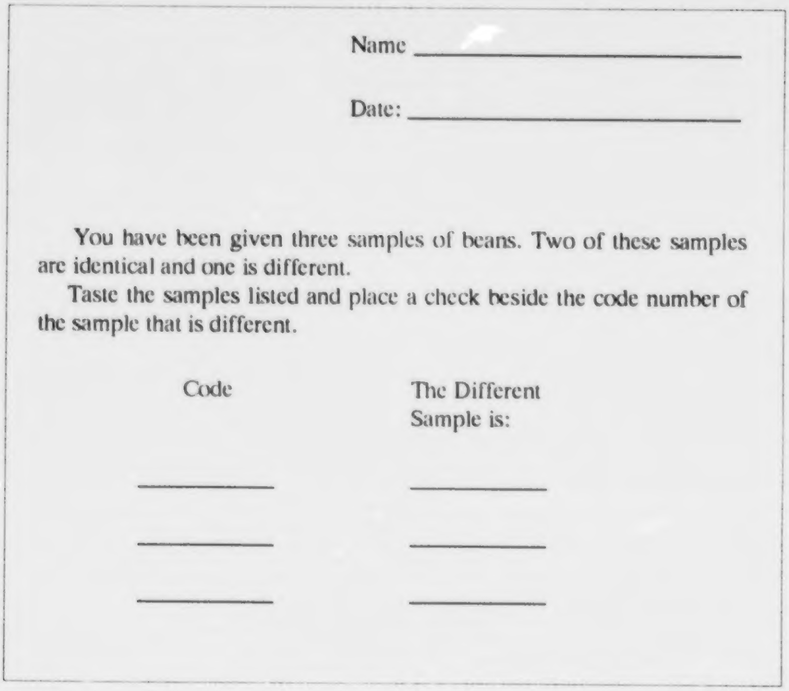
A triangle test was conducted to determine whether black beans that had received a prestorage heat treatment were noticeably different from untreated beans, after both had been stored under the same conditions for six months. Each bean sample was cooked to its optimum doneness following a standard procedure.

An in-house panel of 36 panelists evaluated the cooked bean samples. Three samples were presented simultaneously to each panelist. Six panelists received each of the six serving orders shown in Table 4. The appropriately coded samples were selected for each panelist and presented accompanied by a ballot on which code numbers were listed in the order for tasting. The ballot used is shown in Figure 11.

When all members of the panel had completed the test, their ballots were marked either correct (+) when the odd sample was correctly identified, or incorrect (-). Results were tabulated as shown in Table 5. Using Statistical Table 7.9 (Appendix 7) the

Table 5
Tabulated Triangle Test Data

Panelist	Result
1	+
2	-
3	-
4	+
5	+
6	+
7	-
8	+
9	-
10	-
11	+
12	-
13	-
14	+
15	-
16	+
17	-
18	+
19	-
20	-
21	+
22	-
23	+
24	+
25	+
26	+
27	-
28	+
29	-
30	-
31	+
32	+
33	-
34	+
35	+
36	+
Total Correct (+) =	20



Name ______________________

Date: ______________________

You have been given three samples of beans. Two of these samples are identical and one is different.

Taste the samples listed and place a check beside the code number of the sample that is different.

Code	The Different Sample is:
________	________
________	________
________	________

Figure 11 Ballot for bean storage pretreatment triangle test

total number of panelists with correct answers (X) was compared to the total number of panelists (n) and the significance level determined.

From Table 7.9 (Appendix 7), it was determined that for 36 panelists and 20 correct responses, the significance level was 0.005.

It was concluded that the samples were significantly different at the 0.005 level of probability, since 20 of the 36 panelists correctly chose the different sample. The beans that had been pretreated were therefore different from the untreated beans after 6 months of storage. The size and type of difference, however, was not known.

7.2.2 Ranking for Intensity Tests

Intensity ranking tests require panelists to order samples according to the perceived intensity of a sensory characteristic. This type of test can be used to obtain preliminary information on product differences, or to screen panelists for their ability to discriminate among samples with known differences. Ranking tests can show where there are perceptible differences in intensity of an attribute among samples, but ranking does not give information about the size of the difference between two samples. Samples ranked one and two, for instance, could have a small but readily perceived difference in intensity, while samples ranked two and three could have a large difference in intensity of the attribute. This would not be evident from the rankings.

General Instructions for Conducting a Ranking Test for Intensity.

Description of panelists' task: Trained panelists are asked to rank coded samples for the intensity of a specific characteristic, by ordering the samples from the most intense to the least intense. Ties are not usually allowed.

Presentation of samples: Three or more samples are presented in identical sample containers, coded with 3-digit random numbers. Each sample is given a different code number. All the samples are simultaneously presented to each panelist in a balanced or random order. The panelists are allowed to re-evaluate the samples as necessary to make the required comparisons among them. An example of a ballot for ranking for intensity is given in Figure 12.

Analysis of data: When all panelists have ranked the samples, the ranks assigned to each sample are totalled. The samples are then tested for significant differences by comparing the rank totals between all possible pairs of samples using the Friedman Test and Statistical Tables 7.3 and 7.4 (Appendix 7). This method of data analysis was used for the ranking for acceptability data, Section 7.1.2. That example should be reviewed for details of the test.

Example of a ranking test used by trained panel to compare bean seedcoat toughness.

A ranking test was conducted to compare the seedcoat toughness of beans which had been stored under four different temperature and humidity conditions for three months. Ten panelists, trained to evaluate seedcoat toughness (Appendix 4), participated in the test. All four coded bean samples were simultaneously presented to each panelist. Each panelist evaluated the samples only once. Panelists were instructed to rank the samples for seedcoat toughness without ties, giving each sample a different rank even if the products seemed to be similar. A rank of 1 was given to the sample with the toughest seedcoat, and a rank of 4 to the sample with the least tough seedcoat. The ballot used is shown in Figure 12.

The ranked values given to each sample were tabulated and totalled as shown in Table 6. The differences between rank total pairs were:

D - A = 36 - 18 = 18
D - B = 36 - 26 = 10
D - C = 36 - 20 = 16
C - A = 20 - 18 = 2
B - C = 26 - 20 = 6
B - A = 26 - 18 = 8

Name: ____________________________

Date: ____________________________

Please evaluate each cooked bean sample for seedcoat toughness. Separate the seedcoat from the cotyledon by biting the beans (2 beans) between the molar teeth and rubbing the cotyledon out between the tongue and palate. Then evaluate the force required to bite through the seedcoat with the front teeth.

Evaluate the samples in the order listed below, from top to bottom, then arrange the samples in order of their seedcoat toughness. Assign the sample with the toughest seedcoat a rank value of 1; the samples with the next toughest seedcoats rank values of 2 and 3 and the sample with the least tough seedcoat a rank of 4.

Code	**Rank assigned**
__________	__________
__________	__________
__________	__________
__________	__________

Figure 12 Ballot for seedcoat toughness ranking test

Table 6
Tabulated Ranking[1] for Intensity Test Data

Panelist	Storage Treatment			
	A	B	C	D
1	1	3	2	4
2	1	2	3	4
3	2	3	1	4
4	3	1	2	4
5	1	3	2	4
6	3	1	2	4
7	2	4	1	3
8	1	2	3	4
9	3	4	2	1
10	1	3	2	4
Rank Total	18	26	20	36

[1] Lowest rank = 1 = toughest seedcoat

Tabulated critical values for $p \leq 0.05$, 10 panelists and 4 samples from Table 7.3 is 15. Only the differences between D and A, and D and C, were significant (*i.e.* larger than 15).

Therefore the seedcoats of bean samples stored under D conditions were not as tough as the seedcoats of samples stored under A and C conditions.

7.2.3 Scoring for Intensity Tests

Scoring tests for intensity measurements require panelists to score samples, on line scales or category scales, for the perceived intensity of a sensory characteristic. Scoring tests measure the amount of difference between samples, and allow samples to be ordered by increasing or decreasing intensity of a characteristic.

General Instructions for Conducting a Scoring Test for Intensity.

Description of panelists' task: Panelists score the perceived intensity of the specific characteristic in each coded sample on an interval scale from low intensity to high (or strong) intensity.

Presentation of samples: Samples are presented in identical sample containers, coded with 3-digit random numbers. Each sample is given a different number. All samples are simultaneously presented to each panelist in a balanced or random order. Panelists are instructed to evaluate each sample independently. In order to minimize intercomparison of samples, the experimenter may present samples one at a time to each panelist, removing each sample after testing and before presenting the next sample. In either case, the panelists are instructed to evaluate each sample, and indicate the intensity of the specified characteristic by checking an appropriate category or by making a vertical mark on a line scale. An example of a category scale used for scoring intensity is shown in Figure 7, Section 6.1.3.

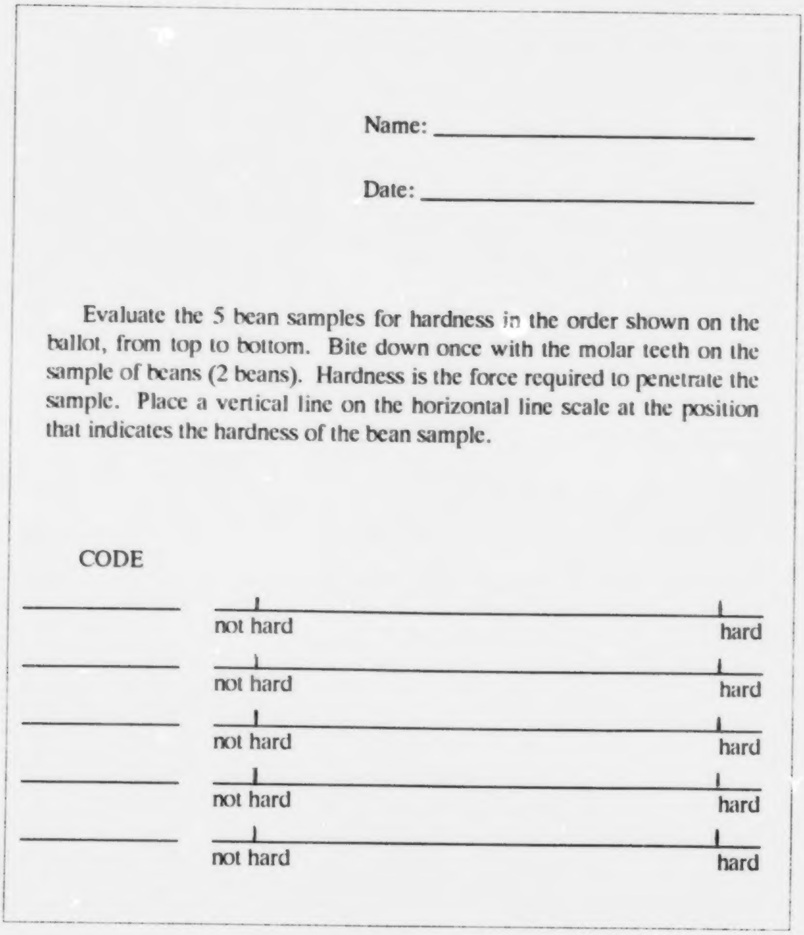
Analysis of data: For analysis of category scale data, the categories are converted to numerical scores by assigning successive numbers to each category; usually the number 1 is given to the category of lowest intensity. For analysis of line scale results, panelists' marks are converted to numerical scores by measuring the distance in cm from the left or lowest intensity point on the scale to the panelists' marks, converting the scores using 0.5 cm = 1 unit score. The numerical scores for each sample are tabulated and analyzed by analysis of variance (ANOVA) to determine if significant differences exist among the samples. Multiple comparison tests can then be used to determine which samples differ from each other.

The entire scoring test is usually repeated on several occasions to obtain several replications of the data. This allows for an accurate measure of experimental error. The use of replicated data also allows the experimenter to assess the performance of the panel by examining the panel results from each replication to see whether significant differences exist among means for each replication.

Example of line scale scoring used by a trained panel to determine bean hardness.

A scoring test was used to compare the hardness of beans cooked for five different cooking times. Samples of one variety of black bean were cooked for 30, 50, 70, 90 and 110 minutes. Starting times were staggered such that all samples finished cooking at the same time.

Seven panelists, who had been trained for texture evaluation of beans, served on the panel. The five bean samples were simultaneously presented to each panelist at each session, in a randomized complete block design. This was repeated two more times, using different code numbers on each occasion, to give three replications. The ballot for scoring, which used a 15 cm line scale, is shown in Figure 13. Panelists scored the samples by placing a vertical line at the appropriate point on each line scale.



Name: ____________________

Date: ____________________

Evaluate the 5 bean samples for hardness in the order shown on the ballot, from top to bottom. Bite down once with the molar teeth on the sample of beans (2 beans). Hardness is the force required to penetrate the sample. Place a vertical line on the horizontal line scale at the position that indicates the hardness of the bean sample.

CODE

not hard
hard
not hard
hard
not hard
hard
not hard
hard
not hard
hard

Figure 13 Ballot for bean hardness scoring test using a line scale [Actual line scale should be 15 cm in length.]

Table 7
Tabulated Scoring for Hardness Test Data[1]

PANELIST	Cooking Time Treatments (min)															
	A (30) Replication			B (50) Replication			C (70) Replication			D (90) Replication			E (110) Replication			Totals
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1	20	24	21	15	19	15	12	18	17	8	12	11	18	16	13	239
2	18	21	22	12	14	8	6	6	8	9	6	9	3	4	6	152
3	13	19	16	6	10	7	5	5	4	5	3	2	5	3	4	107
4	19	10	15	13	6	10	8	5	3	6	4	7	5	3	4	118
5	19	18	24	4	13	9	2	10	7	7	2	7	4	6	12	144
6	20	23	19	17	20	18	8	8	15	5	18	10	14	7	7	209
7	20	16	19	11	13	6	8	6	4	6	6	5	4	4	9	137
Treatment by Replication Total	129	131	136	78	95	73	49	58	58	46	51	51	53	43	55	
													Grand Total			1106

Treatment Total	A=396	B=246	C=165	D=148	E=151
(Mean)	(18.9)	(11.7)	(7.9)	(7.0)	(7.2)

Replication Total[2]	Rep 1 =355	Rep 2 = 378	Rep 3 = 373
(Mean)	(10.1)	(10.8)	(10.7)

[1] Highest score = 30 = hard

[2] Replication totals are for each replication over all treatments

Numerical scores were determined by measuring the distance from the left hand end of the scale to the mark, in 0.5 cm units. A measured distance of 10 cm was therefore equal to a score of 20. Data were tabulated as shown in Table 7 and analyzed by a two-way analysis of variance. The effects of treatments (samples), panelists, replications and interactions were partitioned out. The analysis was similar to that used for the hedonic test. That example should be reviewed for details of the ANOVA (Section 7.1.3).

For the analysis of variance the following calculations were made:

Correction Factor:

$$CF = \frac{1106^2}{105}$$

$$= 11649.87$$

Total Sum of Squares:

$$SS(T) = (20^2 + 24^2 + ... + 4^2 + 9^2) - 11649.87$$

$$= 15522 - 11649.87$$

$$= 3872.13$$

Treatment Sum of Squares:

$$SS(Tr) = \frac{396^2 + 246^2 + 165^2 + 148^2 + 151^2}{21} - 11649.87$$

$$= 13774.38 - 11649.87$$

$$= 2124.51$$

Panelist Sum of Squares:

$$SS(\mathrm{P}) = \frac{239^2 + 152^2 + \ldots + 137^2}{15} - 11649.87$$

$$= 12585.60 - 11649.87$$

$$= 935.73$$

Replication Sum of Squares:

$$SS(\mathrm{R}) = \frac{\Sigma\,(\text{each replication total}^2)}{\text{number of responses in each replication total}} - \mathrm{CF}$$

$$= \frac{355^2 + 378^2 + 373^2}{35} - 11649.87$$

$$= 11658.23 - 11649.87$$

$$= 8.36$$

Error Sum of Squares:

$$SS(\mathrm{E}) = SS(\mathrm{T}) - SS(\mathrm{Tr}) - SS(\mathrm{P}) - SS(\mathrm{R})$$

$$= 3872.13 - 2124.51 - 935.73 - 8.36$$

$$= 803.53$$

The mean square (*MS*) values were calculated by dividing the *SS* values by their respective degrees of freedom. Degrees of freedom (df) were as follows:

Total Degrees of Freedom, df(T) = 105 - 1 = 104

Treatment Degrees of Freedom, df(Tr) = 5 - 1 = 4

Panelist Degrees of Freedom, df(P) = 7 - 1 = 6

Replication Degrees of Freedom, df(R) = 3 - 1 = 2

Error Degrees of Freedom, df(E) = df(T) - df(Tr) - df(P) - df(R)

= 104 - 4 - 6 - 2

= 92

Mean Squares were then calculated as shown:

$$MS\,(\mathrm{Tr}) = \frac{2124.51}{4}$$

$$= 531.13$$

$$MS\,(\mathrm{P}) = \frac{935.73}{6}$$

$$= 155.96$$

$$MS\,(\mathrm{R}) = \frac{8.36}{2}$$

$$= 4.18$$

$$MS\,(\mathrm{E}) = \frac{803.53}{92}$$

$$= 8.73$$

The F ratios were calculated by dividing the MS for panelists by the *MS* for error, the MS for treatments by the MS for error, and the *MS* for replications by the MS for error. The tabular F ratios were obtained from Statistical Tables 7.5 and 7.6 (Appendix 7) of the F distribution. Since actual error degrees of freedom (92) are not listed in the table, F values for 92 df were extrapolated from those given. In this example F ratios were compared to the tabular values of F for a 1% level of significance ($p \leq .01$), Table 7.6. F ratios for the main effects of panelists, treatments and replications are shown in Table 8. Calculated F ratios for treatments and panelists were much greater than the tabulated F ratios, indicating a highly significant effect of both treatments and panelists. The replication main effect was not significant.

The significant panelist effect could mean that the panelists scored the samples in the same order, but that some panelists used different parts of the scale. Therefore, the actual scores given to the samples differed. Since there were large significant differences due to both panelists and treatments, it is possible that some of these differences were due to an interaction. A significant interaction would indicate that the panelists were not all scoring the samples in the same order. For examination of this interaction it was necessary to calculate the sum of squares for the interaction between panelists and treatments. Data from the original tabulated data (Table 7) were totalled to obtain a treatment total for each panelist combined over all three replications. These data are shown in Table 9.

To calculate the treatment by panelist interaction the following calculations were needed:

Table 8
ANOVA Table I Scoring for Hardness Test

Source of Variation	df	SS	MS	F Calculated	F Tabular ($p \leq .01$)
Total	104	3872.13			
Treatments	4	2124.51	531.13	60.84	3.56
Panelists	6	935.73	155.96	17.86	3.03
Replications	2	8.36	4.18	0.48	4.88
Error	92	803.53	8.73		

Table 9
Data Matrix of Treatment Totals for Each Panelist

Panelists	Cooking Time Treatment (min) A (30)	B (50)	C (70)	D (90)	E (110)
1	65	49	47	31	47
2	61	34	20	24	13
3	48	23	14	10	12
4	44	29	16	17	12
5	61	26	19	16	22
6	62	55	31	33	28
7	55	30	18	17	17

Treatment x Panelist Matrix, Total Sum of Squares:

$$SST(\text{TrxP}) = \frac{\Sigma\,(\text{treatment total for each panelist}^2)}{\text{number of replications}} - \text{CF}$$

$$= \frac{65^2 + 61^2 + \ldots + 28^2 + 17^2}{3} - 11649.87$$

$$= 14931.33 - 11649.87$$

$$= 3281.46$$

Interaction Sum of Squares:

$$SS(\text{TrxP}) = SST\,(\text{TrxP}) - SS(\text{P}) - SS(\text{Tr})$$

$$= 3281.46 - 935.73 - 2124.51$$

$$= 221.22$$

Interaction Degrees of Freedom:

$$\text{df(TrxP)} = \text{df(treatments)} \times \text{df(panelists)}$$
$$= 4 \times 6$$
$$= 24$$

The degrees of freedom and the sum of squares for the interaction between panelists and treatments were then added to the ANOVA table and the mean square calculated (Table 10). The main effects of treatments and panelists and the interaction effect of panelists with treatments were tested with a new error mean square. This new error mean square was calculated by subtracting the Treatment *SS*, Panelist *SS*, Replication *SS* and the Interaction (TrxP) *SS* from the Total SS. The new degrees of freedom for error were calculated by subtracting from the total df, the df for Treatments, Panelists, Replication and Interaction (TrxP). These values were placed in the second ANOVA Table (Table 10).

Table 10
ANOVA Table II Scoring for Hardness Test

Source of Variation	df	SS	MS	F Calculated	F Tabular (p ≤.01)
Total	104	3872.13			
Treatments	4	2124.51	531.13	62.05	3.63
Panelists	6	935.73	155.96	18.22	3.10
Replications	2	8.36	4.18	0.49	4.96
TrxP	24	221.22	9.22	1.08	2.10
Error	68	582.31	8.56		

The treatment by panelist interaction was not significant, therefore, the significant panelist effect indicated that the panelists scored the treatments in the same order. Some panelists may, however, have scored the samples using different parts of the scale. For example, one panelist may have scored all the samples using the upper end of the scale only while others may have used the central portion of the scale, resulting in samples which were scored in the same order but with different numerical scores. A multiple comparison test of the panelists' mean scores could be used to discover where the differences among panelists exist. This would be useful during panel training to determine which panelists were scoring samples, or using the scale differently, from others. During studies, however, it is usually the specific treatment differences which are of interest. The absence of a replication effect and of a significant treatment x panelist interaction confirmed the consistency of the panel performance in the example.

The ANOVA indicated that there was a significant difference in the hardness of the four bean samples. To determine which treatments differed significantly from the others, Tukey's multiple comparison test and Tables 7.10 and 7.11 (Appendix 7) were used. Tukey's test is similar to Duncan's test (Section 7.1.3). Pairwise comparisons between all of the means are tested against a calculated range value. If the difference between pairs of means is larger than the range value, the means are significantly different. However, whereas Duncan's test involves the calculation of a number of range values, only a single range value is computed for Tukey's test. Any two means with a difference greater than the range value are significantly different. To carry out this test, treatment means were arranged in order of size as shown:

Cooking Treatments	A	B	C	E	D
Hardness Means	18.9	11.7	7.9	7.2	7.0

The standard error of the sample (treatment) means was estimated by:

$$\text{Standard Error (SE)} = \sqrt{\frac{MS(\text{E})}{n}}$$

where MS(E) is taken from the final ANOVA table (Table 10) and n is the number of responses per treatment.

$$\text{SE} = \sqrt{\frac{MS(\text{E})}{\text{n}}}$$

$$= \sqrt{\frac{8.56}{21}}$$

$$= \sqrt{0.41}$$

$$= 0.64$$

The range value was calculated from the following equation:

$$\text{Range value} = \text{Q(SE)}$$

$$= \text{Q}(0.64)$$

The Q value was obtained from Table 7.11 (Appendix 7) with 68 df(E), 5 treatments and the same level of significance as the ANOVA ($p \leq .01$). Thus, Q = 4.80 (extrapolated from the table).

$$\text{Range value} = 4.80\ (0.64)$$

$$= 3.07$$

Any two sample means which differed by a value greater than the range value, 3.07, were significantly different at the 1% level. All sample means were compared as follows:

A - D = 18.9 - 7.0 = 11.9 > 3.07

A - E = 18.9 - 7.2 = 11.7 > 3.07

A - C = 18.9 - 7.9 = 11.0 > 3.07

A - B = 18.9 - 11.7 = 7.2 > 3.07

B - D = 11.7 - 7.0 = 4.7 > 3.07

B - E = 11.7 - 7.2 = 4.5 > 3.07

B - C = 11.7 - 7.9 = 3.8 > 3.07

C - D = 7.9 - 7.0 = 0.9 < 3.07

C - E = 7.9 - 7.2 = 0.7 < 3.07

E - D = 7.2 - 7.0 = 0.2 < 3.07

Samples A and B were significantly different from each other and all other samples. Samples C, E and D were not significantly different from each other. The significant differences among the means were shown by underlining together those means which were not significantly different at the 1% level of probability.

Cooking Treatments	A	B	C	E	D
Treatment Means	18.9	11.7	7.9	7.2	7.0

Black beans cooked for 30 min (A) were harder than beans cooked for 50 min (B), 70 min (C), 90 min (D) or 110 min (E). Black beans cooked for 50 min (B) were significantly harder than beans cooked for 70 min (C), 90 min (D) or 110 min (E). However, beans cooked for 70 (C), 90 (D) or 110 (E) minutes did not differ in hardness.

7.2.4 Descriptive Tests

Descriptive tests are similar to scoring for intensity tests except that panelists score the intensity of a number of sample characteristics rather than just one characteristic. Trained panelists provide a total sensory description of the sample, including appearance, odour, flavour, texture and aftertaste. There are many types of descriptive tests including the Flavour Profile (Pangborn, 1986; Stone and Sidel, 1985; Powers, 1984; Moskowitz, 1983; IFT, 1981; ASTM, 1968; Amerine *et al.*, 1965; Caul, 1957; Cairncross and Sjostrom, 1950), the Texture Profile (Pangborn, 1986; Stone and Sidel, 1985; Moskowitz, 1983; IFT, 1981; Civille and Szczesniak, 1973; Brandt et al., 1963; Szczesniak, 1963; Szczesniak et al., 1963) and Quantitative Descriptive Analysis (Pangborn, 1986; Moskowitz, 1983; IFT, 1981; Zook and Wessman, 1977; Stone *et al.*, 1980, 1974). These methods will not be described in this manual but the references listed provide discussions and explanations of the techniques.

◆ *Chapter 8*

Planning A Sensory Experiment

In planning a sensory experiment, all of the factors discussed in the previous sections of this manual should be considered carefully. With these considerations in mind, specific tests and appropriate methods of statistical analysis can be chosen. To facilitate planning and conducting of sensory experiments, especially by researchers who are new to this area, a number of tests have been described in detail. Following the step-by-step descriptions given for each test should assist with planning for similar types of testing.

Planning for a sensory experiment should include the steps outlined below:

1) Define the specific objectives of the experiment. Clarify questions to be answered (hypotheses to be tested) and state them clearly.

2) Identify the constraints on the experiment: cost limits, availability of materials, equipment, panelists and time.

3) Choose the type of test and panel to be used. Design the ballot.

4) Design the experimental procedures so that, wherever possible, variables not being tested will be controlled, and panel results will not be biased. Randomization of experimental factors that could bias results, such as the order of sample preparation and presentation, should be planned.

5) Decide on the statistical methods to be used, keeping in mind the objectives of the project, the type of test and type of panel.

6) Prepare the forms to be used for recording sensory data. Data should be recorded in a way that makes it convenient to do the statistical analyses.

7) Plan for recruiting and orienting panelists; also, screening and training of panelists, if required.

8) Do a trial run before proceeding with the experiment, to check the appropriateness of sample preparation and presentation procedures and the ballot.

APPENDICES

APPENDIX 1

Basic Taste Recognition Test

The following concentrations of the four basic tastes of sweet, sour, salty, and bitter can be used for recognition tests.

Basic Taste	Substance	Concentration
Sweet	sucrose	1.0% w/v (2.5 g/250 mL)
Salty	sodium chloride	0.2% w/v (0.5 g/250 mL)
Sour	citric acid	0.04% w/v (0.1 g/250 mL)
Bitter	caffeine	0.05% w/v (0.125 g/250 mL)
	or	
	quinine sulfate	0.00125% w/v (0.003 g/250 mL)

These solutions are prepared with distilled water and should be prepared the day before and allowed to equilibrate overnight. Approximately 25-30 mL of solution is needed per panelist. The solutions are portioned into individual coded sample cups for tasting. 1-2 water blanks are prepared and randomly placed among the 4 basic taste solutions. The coded samples should be presented in a different random order to each panelist. Panelists should be instructed to rinse the mouth with water between samples and clear the mouth with crackers if necessary. An example of a ballot is shown on the next page.

Panelists should be informed about their performance immediately following the test. Poor performers could be allowed to repeat the test on another day following some initial discussion about the basic taste sensations and how they are perceived in the tongue and mouth. Panelists who are unable to identify any of the basic taste solutions may be ageusic (lack of taste sensitivity) and would not be good candidates for taste panels.

APPENDIX 1 (cont.)

Ballot for Basic Taste Recognition Test

Name: ______________________________

Date: ______________________________

Basic Taste Recognition

Please taste each of the solutions in the order indicated on the ballot, from top to bottom. The solutions may taste sweet, sour, salty or bitter. There may be one or more samples of only water among the basic taste solutions. Identify the taste solution in each coded cup. Rinse your mouth with water before you begin tasting and also between each sample. Crackers are also provided to clear the mouth between samples.

Code	Taste
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________

APPENDIX 2

Basic Odour Recognition Test

Common household substances can be used for odour recognition testing. The odourous substances (10-15) should be placed in dark coloured (clear vials may be wrapped in aluminum foil) glass vials or test tubes to mask any visual cues, and tightly capped. Liquids may be poured onto a cotton ball in the tube, while solids can be placed directly into the tube and covered with a cotton ball or square of cheesecloth. Vials or tubes should be filled 1/4 - 1/2 full in order to leave a headspace above the sample for volatiles to concentrate.

Panelists are instructed to bring the vial to their nose, remove the lid and take 3 short sniffs. Then, they should record the name of the odour, or a related odour if they cannot identify the exact name, beside the sample code on the ballot. For example, spicy if they cannot name the exact spice. When interpreting results, the panel leader can give a full score to a correct name, and a half score to a related name. An example of a ballot is shown on the next page.

Panelists should be informed about their performance immediately following the test. Those who have difficulty identifying the substances may just need more practice and could be allowed to repeat the test on another day. Odour and flavour language, as any other language, will improve with practice. Panelists who are unable to smell many of the substances are likely anosmic or may have nasal or sinus congestion and will likely not be good candidates for odour or flavour panels.

Example of substances which have been used are listed below:

Substance	Odour	Possible related odours
vinegar	sour, acetic acid	pickles
coffee	coffee	roasted
onion	onion	sulfury
cloves	cloves, eugenol	spicy, cinnamon
aniseed	anethol, anise	liquorice
cinnamon	cinnamon, eugenol	spicy, cloves
vanilla	vanilla	sweet
black pepper	pepper	spicy
prepared mustard	mustard	pickles
acetone	acetone	nail polish remover
alcohol	alcohol, ethanol	vodka
almond extract	almond	sweet
garlic	garlic, allicin	sulfury
lemon	lemon, sour, acid	citrus
honey	honey	sweet

APPENDIX 2 (cont.)

Ballot for Basic Odour Recognition Test

Name:______________________________

Date: ______________________________

Basic Odour Recognition

The covered vials contain odourous substances commonly found in the home or workplace. Bring the vial to your nose, remove the cap, take 3 short sniffs and try to identify the odour. If you cannot think of the exact name of the substance, try to describe something which this odour reminds you of.

Code	Odour
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________

APPENDIX 3

Training and Monitoring a Bean Texture Panel

A sensory panel was trained specifically for texture evaluation of cooked beans at INCAP. The textural characteristics to be evaluated and the techniques for evaluation of the beans (Appendix 4) were first developed by a trained sensory panel in the Department of Foods and Nutrition at the University of Manitoba. Bean samples were evaluated using a line scale. Food references were also selected (Appendix 5) to anchor the endpoints of the line scale for each textural characteristic, except chewiness. The INCAP panelists were trained using the techniques, ballot and the line scale food references developed in Manitoba for each characteristic. The ballot is shown in Appendix 6.

Training began by presenting panelists with the end point references for each of the texture characteristics to be examined (Appendix 5). Each panelist was then presented with a tray containing a ballot, directions for evaluating the specific textural characteristics and the reference samples. Definitions of the textural characteristics were reviewed by the panel leader and the techniques to be used in the evaluation process were illustrated. Each panelist practised the techniques using the reference samples. After discussion to ensure that the panelists understood the procedures, cooked bean samples that varied greatly in the textural parameters being examined were presented for evaluation and scored on the line scale a number of times. Thus, panelists received experience both in evaluating the intensity of the specific textural characteristics in beans and in using a line scale for scoring the samples.

After the bean samples had been evaluated, marks on the line scales were converted to numerical scores by the panelists or panel leader, measuring the distance in cm and converting the scores using 0.5cm = 1 unit score. Scores for each panelist were listed on a blackboard for discussion and comparison. Although actual scores varied from one panelist to another, most of the panelists achieved a consistent ordering of the bean samples. It is more important for the relationship between the products to be consistent (ie. sample A is always scored as being more soft than sample B) and for individual panelists to be consistent over replicate tests, than it is for all the panelists to give the samples identical scores. However, training should, ideally, bring the panelists' scores closer together. For those who had scored products in the wrong order, definitions and evaluation techniques were reviewed by the panel leader and the panelists evaluated the samples again. The same training procedure was repeated, using comparable bean samples, for several sessions (days) until the panelists were comfortable with the techniques and the repeatability of their scores was improved.

The next step in the training of the texture panel at INCAP was to have the panel evaluate a variety of cooked black bean samples which had less obvious textural differences, along with samples with large differences in texture. For example, for hardness evaluation, samples which were obviously under-cooked (hard), optimally cooked and over-cooked (soft) were prepared and served along with samples that had varying degrees of hardness.

To monitor the panelists' performance, the same six bean samples were evaluated on four different occasions. The samples were evaluated for hardness, particle size, seedcoat toughness and chewiness, and were prepared to have a wide range of differences in each of these attributes. An analysis of variance with 6 treatments and 4 replications was used to evaluate the data for each panelist individually, for each characteristic measured. Treatment F values were calculated for each panelist's scores, and used as a measure of the panelist's ability to discriminate among the bean samples and to replicate his/her judgements for each attribute. Characteristics that required more training (ie. many panelists scored them inconsistently) were also identified. The results of these analyses were discussed with the panel to provide an incentive for panelists to improve or maintain their performance. At a later time a second panel evaluation was conducted. Panel training was complete when the majority of the panelists could discriminate between samples without difficulty and could reproduce their scores consistently. Panelists who were having problems and could not replicate their judgements were released from the panel.

APPENDIX 4

Techniques for Evaluating Textural Characteristics of Cooked Beans

HARDNESS: Bite down once with the molar teeth on the sample of beans (2 beans) and evaluate the force required to penetrate the sample.

PARTICLE SIZE: Chew the sample (2 beans) for only 2-3 chews between the molar teeth, and then rub the cotyledon between the tongue and palate and assess the size of the particles which are most apparent.

SEEDCOAT TOUGHNESS: Separate the seedcoat from the cotyledon by biting the beans (2 beans) between the molar teeth and rubbing the cotyledon out between the tongue and palate. Then evaluate the force required to bite through the seedcoat with the front teeth.

CHEWINESS: Place a sample of beans (2 beans) in your mouth and chew at a constant rate (1 chew per second), counting the number of chews until the sample is ready for swallowing.

APPENDIX 5

Food References Used for Bean Texture Panels

Textural Characteristic[1]	End Points	Reference
Hardness	soft	cream cheese - 1 cm cube[3]
	hard	parmesan cheese - 1 cm cube[3]
Particle[2] Size	smooth	butter - 1 cm cube[3]
	chunky	coarsely chopped peanuts
Seedcoat Toughness	tender seedcoat	black-eyed beans (cooked 2 hr)
	tough seedcoat	navy beans ("Chapin brand") (cooked 1 hr. 50 min)

[1] References for chewiness are not included as a chew count was used as a measure of chewiness

[2] Additional references of starchy (5% $^{w}/_{v}$ slurry of cornstarch in water) and grainy (cooked semolina - cream of wheat) were used during training.

[3] Taken directly from refrigerated storage and served. All others served at room temperature.

APPENDIX 6

Line Scale Ballot Used for Bean Texture Panels

Using the techniques provided for evaluating texture, evaluate the samples according to the following parameters. First, evaluate the reference samples to establish reference points, and then evaluate the coded samples. Mark the relative intensity of the coded bean samples on each scale, placing the code number of the sample above the mark.

INITIAL BITE

Hardness

soft — hard

MASTICATORY PHASE

Particle Size

smooth — chunky

Seedcoat Toughness

tender (barely distinguishable from cotyledons) — tough (leathery)

CHEWINESS

Code	**Number of chews**

APPENDIX 7

STATISTICAL TABLES

The authors wish to thank those who have granted permission for the use of the following tables:

Tables 7.2 & 7.9 — Reproduced from E.B. Roessler, R.M. Pangborn, J.L. Sidel and H. Stone, "Expanded Statistical Tables for Estimating Significance in Paired-Preference, Duo-Trio and Triangle Tests". *Journal of Food Science*, 43:940-943,947, 1978.

Tables 7.3 & 7.4 — Reproduced from G.J. Newell and J.D. MacFarlane, "Expanded Tables for Multiple Comparison Procedures in the Analysis of Ranked Data". *Journal of Food Science*, 52:1721-1725, 1987.

Tables 7.5 & 7.6 — Reproduced from M. Merrington, C.M. Thompson and E.S. Pearson, "Tables of Percentage Points of the Inverted Beta (F) Distribution". *Biometrica* 33:73-88, 1943, with permission from the Biometrika Trustees.

Tables 7.7 & 7.8 — Reproduced from H.L. Harter, "Critical Values for Duncan's New Multiple Range Test". *Biometrics* 16:671-685, 1960, with permission from The Biometrics Society.

Tables 7.10 & 7.11 — Reproduced from E.S. Pearson and N.D. Hartley (Ed.). Table 29 in "Biometrika Tables for Statisticians", Vol. 1, Third Edition (1966), with permission from the Biometrika Trustees.

TABLE 7.1
Random Numbers Table

92 73 35 54 98	26 56 39 28 82	91 43 06 93 24	72 00 82 80 75	85 19 70 64 43
16 51 87 38 01	90 16 71 58 81	97 58 00 77 86	36 00 66 83 36	01 19 53 58 68
33 17 94 03 07	27 41 40 81 74	55 96 82 24 83	90 41 63 36 50	48 18 86 67 17
27 57 83 36 77	07 53 58 09 94	24 00 21 76 21	58 55 77 99 65	52 38 17 40 90
61 29 94 65 15	91 54 01 44 49	97 49 97 99 48	94 72 47 63 35	36 06 68 95 71
83 81 58 29 20	93 72 49 83 27	06 73 46 53 80	05 74 62 18 31	95 28 64 99 86
19 73 59 65 95	16 27 57 65 41	36 49 07 54 07	43 91 74 14 40	95 28 57 76 51
32 47 42 59 60	96 19 56 32 02	16 03 06 41 98	79 75 15 66 64	63 29 50 27 92
19 44 93 63 76	45 72 47 25 60	18 69 63 00 95	80 72 06 98 19	73 61 99 74 05
75 87 08 73 42	32 58 61 49 91	95 40 38 76 23	84 49 63 08 97	68 61 99 05 55
09 88 60 27 23	44 53 22 40 86	35 87 80 47 11	96 23 64 69 33	80 49 89 24 01
40 69 87 66 60	64 95 99 77 03	79 67 71 05 99	00 48 94 87 42	18 98 77 33 81
53 54 06 47 69	72 03 60 45 24	21 42 53 79 70	87 15 89 22 45	71 80 10 29 10
48 52 50 77 53	33 50 89 98 24	19 74 34 26 41	12 11 50 40 11	58 08 97 80 25
91 52 19 84 90	77 32 15 76 35	44 71 26 06 01	91 57 51 20 03	84 44 32 90 30
56 32 08 70 52	62 85 85 53 60	00 26 26 76 80	43 56 95 78 65	20 81 11 25 21
68 54 50 25 19	38 80 73 89 22	63 34 31 24 12	88 25 99 34 44	19 08 20 74 51
41 46 28 06 13	95 62 19 35 63	90 94 04 59 81	16 57 45 02 98	97 35 35 17 44
11 91 09 05 33	02 68 19 97 21	67 79 26 16 91	54 10 56 58 61	31 24 22 34 95
78 96 49 50 26	57 35 48 61 03	38 80 07 08 00	83 09 42 96 63	45 24 01 96 21
39 00 27 47 60	83 45 25 28 77	57 99 02 56 59	98 38 25 89 65	07 91 84 67 81
58 08 80 92 56	85 62 98 67 67	95 03 17 42 26	96 44 19 06 74	31 39 97 94 27
56 81 87 37 10	56 34 49 22 78	50 96 35 45 40	21 51 98 10 18	02 06 48 96 58
36 35 32 43 44	69 88 75 56 07	86 01 84 12 25	39 71 66 87 17	89 23 53 07 31
51 93 66 36 87	42 90 04 20 32	09 36 63 34 92	02 34 96 00 65	37 61 22 15 69
68 28 29 88 56	53 00 66 27 29	08 05 73 10 47	05 21 45 98 77	01 01 48 45 39
73 21 85 37 49	94 48 60 83 76	34 69 65 58 41	14 79 53 32 88	87 69 97 80 92
02 50 08 84 77	23 90 50 36 16	69 81 53 97 43	48 06 85 37 06	81 00 48 13 19
28 49 35 23 70	84 43 13 05 94	47 13 65 25 13	95 29 93 65 45	50 12 61 20 06
84 95 64 21 30	40 87 75 49 77	07 51 00 99 20	55 96 12 18 61	80 37 92 91 91
61 67 92 67 17	03 92 42 50 75	01 98 45 10 05	78 87 90 47 73	02 98 19 89 04
25 01 68 34 92	17 99 59 73 84	82 75 01 78 64	10 09 07 09 56	08 95 86 18 94
20 72 90 17 09	02 64 44 68 72	65 83 44 44 05	96 85 90 55 00	36 28 10 04 88
72 30 42 62 43	21 12 23 11 00	08 84 12 22 08	32 56 55 63 16	06 86 46 28 40
79 89 79 56 56	52 17 02 56 37	33 20 07 40 39	35 33 98 80 47	54 03 31 08 17
41 32 02 75 96	74 65 72 58 01	74 79 29 05 29	97 26 91 36 36	20 07 46 35 19
24 59 60 88 81	13 46 20 67 80	84 81 97 94 32	14 22 07 84 10	75 77 18 14 65
48 51 76 58 18	11 55 87 94 27	60 26 92 09 00	71 97 72 05 30	14 21 83 99 46
27 05 35 96 75	06 17 26 28 05	31 20 79 16 72	27 09 62 94 26	06 78 56 42 82
19 73 48 30 37	22 73 62 86 68	06 92 82 65 10	44 54 09 11 70	91 01 26 15 61
10 59 61 30 64	18 52 97 24 80	81 40 99 83 02	28 97 79 99 29	82 37 41 79 33
06 20 64 72 63	79 92 43 52 33	86 12 76 48 29	77 02 34 49 00	40 83 62 63 94
92 42 30 97 23	74 83 22 11 41	73 53 48 10 58	00 06 97 25 53	36 01 06 61 74
86 79 11 15 34	00 26 83 82 10	48 32 37 41 48	60 89 27 58 07	74 48 23 98 74
60 88 55 02 30	59 97 88 69 09	05 03 63 84 72	26 71 02 18 54	16 61 94 44 07
74 09 21 65 09	32 54 78 17 61	41 84 72 37 06	92 44 02 30 78	43 56 00 74 48
90 75 09 73 22	45 70 71 03 26	14 31 86 14 46	21 97 96 81 73	88 04 88 37 99
14 72 51 66 03	84 60 44 03 15	66 73 62 29 38	49 58 81 94 87	98 66 17 22 98
23 20 32 85 06	98 69 68 60 11	23 40 29 11 30	95 57 54 85 83	44 82 12 48 80
47 71 02 68 97	71 72 57 50 28	00 05 44 94 39	01 47 28 79 18	60 97 87 65 41

TABLE 7.1 (cont.)
Random Numbers Table

36 27 64 92 29	10 13 13 26 18	70 49 46 76 82	40 95 03 23 50	95 49 81 65 59
89 98 18 56 63	44 12 36 38 45	79 86 16 35 18	92 77 77 81 35	60 08 00 03 89
41 56 64 46 30	83 32 55 94 83	92 77 01 10 34	85 18 90 52 66	85 96 17 94 52
46 01 03 34 17	36 45 23 42 71	62 83 89 00 76	26 12 30 39 49	24 45 01 47 08
74 19 18 58 38	45 95 89 90 57	17 56 42 25 50	14 15 06 51 15	00 80 71 54 30
58 35 06 11 82	58 02 82 92 04	48 49 46 13 05	70 39 51 64 27	88 99 50 78 53
25 39 08 65 10	42 66 62 76 78	55 98 14 69 20	57 98 02 26 10	86 10 72 87 40
45 81 79 85 17	78 41 23 62 38	75 66 65 53 81	45 92 91 30 40	87 51 94 08 14
66 07 40 74 42	01 84 30 71 03	26 95 66 53 08	78 28 19 29 37	31 49 85 07 24
48 08 38 86 84	11 67 13 08 22	18 03 62 21 80	06 75 58 50 56	79 84 02 22 01
64 56 10 04 14	05 23 15 01 16	36 38 63 84 10	73 21 64 74 12	75 38 41 38 45
43 82 44 80 16	80 95 26 12 72	69 47 33 42 65	39 03 27 23 32	22 20 18 41 18
68 24 81 78 90	72 77 32 46 74	56 21 46 71 66	80 61 49 78 64	39 32 85 84 47
68 39 42 15 64	74 50 44 54 98	64 66 66 08 96	82 57 07 60 73	88 01 18 68 21
84 10 95 26 08	10 51 65 03 85	35 51 70 18 40	67 31 60 46 91	98 60 80 34 35
06 82 42 61 36	85 62 42 25 91	12 13 14 30 41	74 21 40 94 50	70 88 69 08 15
23 09 79 03 13	45 21 55 04 02	42 55 60 88 50	73 80 64 42 22	18 99 34 87 84
87 83 21 08 77	06 25 54 97 15	60 61 04 68 49	94 76 20 78 36	26 48 03 59 72
84 76 40 56 55	88 68 81 01 63	38 45 47 59 48	57 03 45 01 48	91 93 68 02 12
53 81 33 01 30	52 33 74 74 56	78 87 62 91 53	23 56 34 35 24	62 89 43 63 96
39 04 99 99 88	08 77 01 10 01	22 64 60 57 25	73 50 67 04 79	38 91 51 29 18
71 26 72 67 25	92 36 01 77 86	19 54 65 51 61	64 49 89 84 19	54 83 92 68 94
50 52 72 95 18	23 65 04 78 73	40 88 56 38 96	89 53 72 54 42	14 48 66 67 26
72 38 35 28 72	87 33 60 04 44	20 76 80 37 19	37 61 47 47 97	48 07 58 03 81
98 96 95 85 40	23 08 04 34 89	88 88 46 92 53	99 19 02 60 25	24 44 06 30 43
10 98 80 95 16	33 67 25 73 98	85 61 04 72 82	39 39 92 82 15	59 88 42 57 39
06 73 69 97 88	78 36 03 05 66	22 61 53 32 48	41 08 33 09 15	77 06 04 87 95
00 49 27 22 93	65 65 06 28 88	43 24 65 96 14	67 19 30 70 86	53 87 46 62 35
76 14 99 63 59	15 25 44 97 49	97 74 51 42 50	30 62 51 65 19	81 76 32 69 78
92 17 79 45 06	87 28 87 91 10	38 13 94 23 00	75 99 63 62 71	72 71 50 44 59
81 84 00 13 70	19 32 41 38 86	21 35 51 07 72	51 18 95 67 31	64 36 88 94 08
18 89 75 41 91	71 50 12 52 67	57 98 66 78 29	43 48 79 20 82	19 92 17 17 81
18 15 54 38 69	21 09 49 46 79	12 96 88 12 82	84 14 34 49 60	61 00 64 97 75
25 67 19 45 22	38 12 15 45 16	81 99 04 02 27	92 61 27 50 95	10 50 92 28 93
50 74 03 59 58	37 11 95 42 71	59 73 50 41 56	44 28 25 37 88	57 95 44 07 53
15 37 18 71 81	88 27 91 67 77	29 54 01 17 25	05 97 46 65 22	80 66 93 02 41
58 27 81 52 71	11 31 35 35 25	77 71 63 11 20	19 38 49 10 37	12 67 47 40 60
02 70 61 10 26	57 74 71 29 69	89 14 30 80 19	62 16 62 63 42	82 19 61 55 80
36 18 22 13 05	55 97 35 51 73	98 46 20 62 13	14 65 07 76 62	32 94 60 23 27
42 30 70 57 81	67 85 97 28 63	68 71 11 44 71	13 69 22 02 86	72 33 05 61 53
77 86 84 73 38	73 00 71 55 84	40 05 62 84 23	25 06 13 79 75	11 59 73 59 61
51 32 38 45 08	73 84 75 01 65	34 49 99 21 38	85 43 74 41 83	22 39 78 24 26
57 00 03 36 50	15 57 08 41 82	62 60 59 57 15	98 97 72 35 69	67 88 05 23 33
02 89 67 41 36	20 49 73 04 57	04 84 24 58 16	46 65 45 92 44	98 38 63 50 84
05 20 98 54 89	50 70 82 03 13	45 99 78 23 57	17 03 45 52 77	34 18 29 96 08
75 09 54 90 05	74 39 32 27 14	10 96 59 97 10	16 60 93 86 21	66 99 07 16 49
34 52 52 21 56	08 54 46 65 05	49 49 38 79 65	49 35 65 65 13	62 75 27 53 39
17 87 53 33 08	15 70 87 09 17	66 10 34 71 89	36 75 40 54 51	08 72 56 36 95
78 95 48 93 70	45 87 35 30 53	51 43 03 73 74	06 00 51 96 96	24 43 31 55 91
13 95 60 19 02	29 79 66 71 11	99 05 27 46 03	18 85 14 23 73	75 85 62 16 80

TABLE 7.2
Two-Tailed Binomial Test
Probability of X or more agreeing judgements in n trials (p=1/2)

n \ X	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
5	625	312	062																																
6		688	219	031																															
7			453	125	016																														
8			727	289	070	008																													
9				508	180	039	004																												
10				754	344	109	021	002																											
11					549	227	065	011	001																										
12					774	388	146	039	006																										
13						581	267	092	022	003																									
14						791	424	180	057	013	002																								
15							607	302	118	035	007	001																							
16							804	454	210	077	021	004	001																						
17								629	332	143	049	013	002																						
18								815	481	238	096	031	008	001																					
19									648	359	167	064	019	004	001																				
20									824	503	263	115	041	012	003																				
21										664	383	189	078	027	007	001																			
22										832	523	286	134	052	017	004	001																		
23											678	405	210	093	035	011	003																		
24											839	541	307	152	064	023	007	002																	
25												690	424	230	108	043	015	004	001																
26												845	557	327	169	076	029	009	002	001															
27													701	443	248	122	052	019	006	002															
28													851	572	345	185	087	036	013	004	001														
29														711	458	265	136	061	024	008	002	001													
30														856	585	362	200	099	043	016	006	001													
31															730	473	281	150	071	030	011	003	001												
32															860	597	377	215	100	050	020	007	002	001											
33																728	487	296	163	080	035	014	005	001											
34																864	608	392	229	121	058	024	009	003	001										
35																	736	500	310	175	090	041	017	006	002										
36																	868	618	405	243	132	065	029	011	004	001									
37																		743	511	324	188	099	047	020	008	003	001								
38																		871	627	418	256	143	073	034	014	005	002								
39																			749	522	337	200	108	053	024	009	003	001							
40																			875	636	430	268	154	081	038	017	006	002	001						
41																				755	533	349	211	117	060	028	012	004	001						
42																				878	644	441	280	164	088	044	020	008	003	001					
43																					761	542	360	222	126	066	032	014	005	002	001				
44																					880	652	461	291	174	096	048	023	010	004	001				
45																						766	551	371	233	135	072	036	016	007	002	001			
46																						883	659	461	302	184	104	054	026	011	005	002	001		
47																							771	560	382	243	144	079	040	018	008	003	001		
48																							885	665	471	312	193	111	059	029	013	006	002	001	
49																								775	568	392	253	152	085	044	021	009	004	001	
50																								888	672	480	322	203	119	065	033	015	007	003	001

* NOTE Initial decimal point has been omitted

TABLE 7.3
Critical Absolute Rank Sum Differences for "All Treatments" Comparisons at 5% Level of Significance

	Number of samples									
Panelists	3	4	5	6	7	8	9	10	11	12
3	6	8	11	13	15	18	20	23	25	28
4	7	10	13	15	18	21	24	27	30	33
5	8	11	14	17	21	24	27	30	34	37
6	9	12	15	19	22	26	30	34	37	42
7	10	13	17	20	24	28	32	36	40	44
8	10	14	18	22	26	30	34	39	43	47
9	10	15	19	23	27	32	36	41	46	50
10	11	15	20	24	29	34	38	43	48	53
11	11	16	21	26	30	35	40	45	51	56
12	12	17	22	27	32	37	42	48	53	58
13	12	18	23	28	33	39	44	50	55	61
14	13	18	24	29	34	40	46	52	57	63
15	13	19	24	30	36	42	47	53	59	66
16	14	19	25	31	37	42	49	55	61	67
17	14	20	26	32	38	44	50	56	63	69
18	15	20	26	32	39	45	51	58	65	71
19	15	21	27	33	40	46	53	60	66	73
20	15	21	28	34	41	47	54	61	68	75
21	16	22	28	35	42	49	56	63	70	77
22	16	22	29	36	43	50	57	64	71	79
23	16	23	30	37	44	51	58	65	73	80
24	17	23	30	37	45	52	59	67	74	82
25	17	24	31	38	46	53	61	68	76	84
26	17	24	32	39	46	54	62	70	77	85
27	18	25	32	40	47	55	63	71	79	87
28	18	25	33	40	48	56	64	72	80	89
29	18	26	33	41	49	57	65	73	82	90
30	19	26	34	42	50	58	66	75	83	92
31	19	27	34	42	51	59	67	76	85	93
32	19	27	35	43	51	60	68	77	86	95
33	20	27	36	44	52	61	70	78	87	96
34	20	28	36	44	53	62	71	79	89	98
35	20	28	37	45	54	63	72	81	90	99
36	20	29	37	46	55	63	73	82	91	100
37	21	29	38	46	55	64	74	83	92	102
38	21	29	38	47	56	65	75	84	94	103
39	21	30	39	48	57	66	76	85	95	105
40	21	30	39	48	57	67	76	86	96	106
41	22	31	40	49	58	68	77	87	97	107
42	22	31	40	49	59	69	78	88	98	109
43	22	31	41	50	60	69	79	89	99	110
44	22	32	41	51	60	70	80	90	101	111
45	23	32	41	51	61	71	81	91	102	112
46	23	32	42	52	62	72	82	92	103	114
47	23	33	42	52	62	72	83	93	104	115
48	23	33	43	53	63	73	84	94	105	116
49	24	33	43	53	64	74	85	95	106	117
50	24	34	44	54	64	75	85	96	107	118
55	25	35	46	56	67	78	90	101	112	124
60	26	37	48	59	70	82	94	105	117	130
65	27	38	50	61	73	85	97	110	122	135
70	28	40	52	64	76	88	101	114	127	140
75	29	41	53	66	79	91	105	118	131	145
80	30	42	55	68	81	94	108	122	136	150
85	31	44	57	70	84	97	111	125	140	154
90	32	45	58	72	86	100	114	129	144	159
95	33	46	60	74	88	103	118	133	148	163
100	34	47	61	76	91	105	121	136	151	167

[a] Exact values adapted from Hollander and Wolfe (1973) are used for up to 15 panelists.

[b] Interpolation may be used for unspecified table values involving more than 50 panelists.

TABLE 7.4
Critical Absolute Rank Sum Differences for "All Treatments" Comparisons at 1% Level of Significance

	Number of samples									
Panelists	3	4	5	6	7	8	9	10	11	12
3	–	9	12	14	17	19	22	24	27	30
4	8	11	14	17	20	23	26	29	32	36
5	9	13	16	19	23	26	30	33	37	41
6	10	14	18	21	25	29	33	37	41	45
7	11	15	19	23	28	32	36	40	45	49
8	12	16	21	25	30	34	39	43	48	53
9	13	17	22	27	32	36	41	46	51	56
10	13	18	23	28	33	38	44	49	54	59
11	14	19	24	30	35	40	46	51	57	63
12	15	20	26	31	37	42	48	54	60	66
13	15	21	27	32	38	44	50	56	62	68
14	16	22	28	34	40	46	52	58	65	71
15	16	22	28	35	41	48	54	60	67	74
16	17	23	30	36	43	49	56	63	70	77
17	17	24	31	37	44	51	58	65	72	79
18	18	25	31	38	45	52	60	67	74	81
19	18	25	32	39	46	54	61	69	76	84
20	19	26	33	40	48	55	63	70	78	86
21	19	27	34	41	49	56	64	72	80	88
22	20	27	35	42	50	58	66	74	82	90
23	20	28	35	43	51	59	67	75	84	92
24	21	28	36	44	52	60	69	77	85	94
25	21	29	37	45	53	62	70	79	87	96
26	22	29	38	46	54	63	71	80	89	98
27	22	30	38	47	55	64	73	82	91	100
28	22	31	39	48	56	65	74	83	92	101
29	23	31	40	48	57	66	75	85	94	103
30	23	32	40	49	58	67	77	86	95	105
31	23	32	41	50	59	69	78	87	97	107
32	24	33	42	51	60	70	79	89	99	108
33	24	33	42	52	61	71	80	90	100	110
34	25	34	43	52	62	72	82	92	102	112
35	25	34	44	53	63	73	83	93	103	113
36	25	35	44	54	64	74	84	94	105	115
37	26	35	45	55	65	75	85	95	106	117
38	26	36	45	55	66	76	86	97	107	118
39	26	36	46	56	66	77	87	98	109	120
40	27	36	47	57	67	78	88	99	110	121
41	27	37	47	57	68	79	90	100	112	123
42	27	37	48	58	69	80	91	102	113	124
43	28	38	48	59	70	81	92	103	114	126
44	28	38	49	60	70	82	93	104	115	127
45	28	39	49	60	71	82	94	105	117	128
46	28	39	50	61	72	83	95	106	118	130
47	29	39	50	62	73	84	96	108	119	131
48	29	40	51	62	74	85	97	109	121	133
49	29	40	51	63	74	86	98	110	122	134
50	30	41	52	63	75	87	99	111	123	135
55	31	43	54	66	79	91	104	116	129	142
60	32	45	57	69	82	95	108	121	135	148
65	34	46	59	72	86	99	113	126	140	154
70	35	48	61	75	89	103	117	131	146	160
75	36	50	64	78	92	106	121	136	151	166
80	37	51	66	80	95	110	125	140	156	171
85	38	53	68	83	98	113	129	144	160	176
90	40	54	70	85	101	116	132	149	165	181
95	41	56	71	87	103	120	136	153	169	186
100	42	57	73	89	106	123	140	157	174	191

[a] Exact values adapted from Hollander and Wolfe (1973) are used for up to 15 panelists.

[b] Interpolation may be used for unspecified table values involving more than 50 panelists.

TABLE 7.5
F Distribution
5% Level of Significance

ν_1 ν_2	1	2	3	4	5	6	7	8	9
1	161·45	199·50	215·71	224·58	230·16	233·99	236·77	238·88	240·54
2	18·513	19·000	19·164	19·247	19·296	19·330	19·353	19·371	19·385
3	10·128	9·5521	9·2766	9·1172	9·0135	8·9406	8·8868	8·8452	8·8123
4	7·7086	6·9443	6·5914	6·3883	6·2560	6·1631	6·0942	6·0410	5·9988
5	6·6079	5·7861	5·4095	5·1922	5·0503	4·9503	4·8759	4·8183	4·7725
6	5·9874	5·1433	4·7571	4·5337	4·3874	4·2839	4·2066	4·1468	4·0990
7	5·5914	4·7374	4·3468	4·1203	3·9715	3·8660	3·7870	3·7257	3·6767
8	5·3177	4·4590	4·0662	3·8378	3·6875	3·5806	3·5005	3·4381	3·3881
9	5·1174	4·2565	3·8626	3·6331	3·4817	3·3738	3·2927	3·2296	3·1789
10	4·9646	4·1028	3·7083	3·4780	3·3258	3·2172	3·1355	3·0717	3·0204
11	4·8443	3·9823	3·5874	3·3567	3·2039	3·0946	3·0123	2·9480	2·8962
12	4·7472	3·8853	3·4903	3·2592	3·1059	2·9961	2·9134	2·8486	2·7964
13	4·6672	3·8056	3·4105	3·1791	3·0254	2·9153	2·8321	2·7669	2·7144
14	4·6001	3·7389	3·3439	3·1122	2·9582	2·8477	2·7642	2·6987	2·6458
15	4·5431	3·6823	3·2874	3·0556	2·9013	2·7905	2·7066	2·6408	2·5876
16	4·4940	3·6337	3·2389	3·0069	2·8524	2·7413	2·6572	2·5911	2·5377
17	4·4513	3·5915	3·1968	2·9647	2·8100	2·6987	2·6143	2·5480	2·4943
18	4·4139	3·5546	3·1599	2·9277	2·7729	2·6613	2·5767	2·5102	2·4563
19	4·3808	3·5219	3·1274	2·8951	2·7401	2·6283	2·5435	2·4768	2·4227
20	4·3513	3·4928	3·0984	2·8661	2·7109	2·5990	2·5140	2·4471	2·3928
21	4·3248	3·4668	3·0725	2·8401	2·6848	2·5727	2·4876	2·4205	2·3661
22	4·3009	3·4434	3·0491	2·8167	2·6613	2·5491	2·4638	2·3965	2·3419
23	4·2793	3·4221	3·0280	2·7955	2·6400	2·5277	2·4422	2·3748	2·3201
24	4·2597	3·4028	3·0088	2·7763	2·6207	2·5082	2·4226	2·3551	2·3002
25	4·2417	3·3852	2·9912	2·7587	2·6030	2·4904	2·4047	2·3371	2·2821
26	4·2252	3·3690	2·9751	2·7426	2·5868	2·4741	2·3883	2·3205	2·2655
27	4·2100	3·3541	2·9604	2·7278	2·5719	2·4591	2·3732	2·3053	2·2501
28	4·1960	3·3404	2·9467	2·7141	2·5581	2·4453	2·3593	2·2913	2·2360
29	4·1830	3·3277	2·9340	2·7014	2·5454	2·4324	2·3463	2·2782	2·2229
30	4·1709	3·3158	2·9223	2·6896	2·5336	2·4205	2·3343	2·2662	2·2107
40	4·0848	3·2317	2·8387	2·6060	2·4495	2·3359	2·2490	2·1802	2·1240
60	4·0012	3·1504	2·7581	2·5252	2·3683	2·2540	2·1665	2·0970	2·0401
120	3·9201	3·0718	2·6802	2·4472	2·2900	2·1750	2·0867	2·0164	1·9588
∞	3·8415	2·9957	2·6049	2·3719	2·2141	2·0986	2·0096	1·9384	1·8799

This table gives the values of F for which $I_F(\nu_1, \nu_2) = 0{\cdot}05$.

TABLE 7.5 (cont.)
F Distribution
5% Level of Significance

ν_1 ν_2	10	12	15	20	24	30	40	60	120	∞
1	241·88	243·91	245·95	248·01	249·05	250·09	251·14	252·20	253·25	254·32
2	19·396	19·413	19·429	19·446	19·454	19·462	19·471	19·479	19·487	19·496
3	8·7855	8·7446	8·7029	8·6602	8·6385	8·6166	8·5944	8·5720	8·5494	8·5265
4	5·9644	5·9117	5·8578	5·8025	5·7744	5·7459	5·7170	5·6878	5·6581	5·6281
5	4·7351	4·6777	4·6188	4·5581	4·5272	4·4957	4·4638	4·4314	4·3984	4·3650
6	4·0600	3·9999	3·9381	3·8742	3·8415	3·8082	3·7743	3·7398	3·7047	3·6688
7	3·6365	3·5747	3·5108	3·4445	3·4105	3·3758	3·3404	3·3043	3·2674	3·2298
8	3·3472	3·2840	3·2184	3·1503	3·1152	3·0794	3·0428	3·0053	2·9669	2·9276
9	3·1373	3·0729	3·0061	2·9365	2·9005	2·8637	2·8259	2·7872	2·7475	2·7067
10	2·9782	2·9130	2·8450	2·7740	2·7372	2·6996	2·6609	2·6211	2·5801	2·5379
11	2·8536	2·7876	2·7186	2·6464	2·6090	2·5705	2·5309	2·4901	2·4480	2·4045
12	2·7534	2·6866	2·6169	2·5436	2·5055	2·4663	2·4259	2·3842	2·3410	2·2962
13	2·6710	2·6037	2·5331	2·4589	2·4202	2·3803	2·3392	2·2966	2·2524	2·2064
14	2·6021	2·5342	2·4630	2·3879	2·3487	2·3082	2·2664	2·2230	2·1778	2·1307
15	2·5437	2·4753	2·4035	2·3275	2·2878	2·2468	2·2043	2·1601	2·1141	2·0658
16	2·4935	2·4247	2·3522	2·2756	2·2354	2·1938	2·1507	2·1058	2·0589	2·0096
17	2·4499	2·3807	2·3077	2·2304	2·1898	2·1477	2·1040	2·0584	2·0107	1·9604
18	2·4117	2·3421	2·2686	2·1906	2·1497	2·1071	2·0629	2·0166	1·9681	1·9168
19	2·3779	2·3080	2·2341	2·1555	2·1141	2·0712	2·0264	1·9796	1·9302	1·8780
20	2·3479	2·2776	2·2033	2·1242	2·0825	2·0391	1·9938	1·9464	1·8963	1·8432
21	2·3210	2·2504	2·1757	2·0960	2·0540	2·0102	1·9645	1·9165	1·8657	1·8117
22	2·2967	2·2258	2·1508	2·0707	2·0283	1·9842	1·9380	1·8895	1·8380	1·7831
23	2·2747	2·2036	2·1282	2·0476	2·0050	1·9605	1·9139	1·8649	1·8128	1·7570
24	2·2547	2·1834	2·1077	2·0267	1·9838	1·9390	1·8920	1·8424	1·7897	1·7331
25	2·2365	2·1649	2·0889	2·0075	1·9643	1·9192	1·8718	1·8217	1·7684	1·7110
26	2·2197	2·1479	2·0716	1·9898	1·9464	1·9010	1·8533	1·8027	1·7488	1·6906
27	2·2043	2·1323	2·0558	1·9736	1·9299	1·8842	1·8361	1·7851	1·7307	1·6717
28	2·1900	2·1179	2·0411	1·9586	1·9147	1·8687	1·8203	1·7689	1·7138	1·6541
29	2·1768	2·1045	2·0275	1·9446	1·9005	1·8543	1·8055	1·7537	1·6981	1·6377
30	2·1646	2·0921	2·0148	1·9317	1·8874	1·8409	1·7918	1·7396	1·6835	1·6223
40	2·0772	2·0035	1·9245	1·8389	1·7929	1·7444	1·6928	1·6373	1·5766	1·5089
60	1·9926	1·9174	1·8364	1·7480	1·7001	1·6491	1·5943	1·5343	1·4673	1·3893
120	1·9105	1·8337	1·7505	1·6587	1·6084	1·5543	1·4952	1·4290	1·3519	1·2539
∞	1·8307	1·7522	1·6664	1·5705	1·5173	1·4591	1·3940	1·3180	1·2214	1·0000

$$F = \frac{s_1^2}{s_2^2} = \frac{\nu_2 S_1}{\nu_1 S_2}.$$

TABLE 7.6
F Distribution
1% Level of Significance

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9
1	4052·2	4999·5	5403·3	5624·6	5763·7	5859·0	5928·3	5981·6	6022·5
2	98·503	99·000	99·166	99·249	99·299	99·332	99·356	99·374	99·388
3	34·116	30·817	29·457	28·710	28·237	27·911	27·672	27·489	27·345
4	21·198	18·000	16·694	15·977	15·522	15·207	14·976	14·799	14·659
5	16·258	13·274	12·060	11·392	10·967	10·672	10·456	10·289	10·158
6	13·745	10·925	9·7795	9·1483	8·7459	8·4661	8·2600	8·1016	7·9761
7	12·246	9·5466	8·4513	7·8467	7·4604	7·1914	6·9928	6·8401	6·7188
8	11·259	8·6491	7·5910	7·0060	6·6318	6·3707	6·1776	6·0289	5·9106
9	10·561	8·0215	6·9919	6·4221	6·0569	5·8018	5·6129	5·4671	5·3511
10	10·044	7·5594	6·5523	5·9943	5·6363	5·3858	5·2001	5·0567	4·9424
11	9·6460	7·2057	6·2167	5·6683	5·3160	5·0692	4·8861	4·7445	4·6315
12	9·3302	6·9266	5·9526	5·4119	5·0643	4·8206	4·6395	4·4994	4·3875
13	9·0738	6·7010	5·7394	5·2053	4·8616	4·6204	4·4410	4·3021	4·1911
14	8·8616	6·5149	5·5639	5·0354	4·6950	4·4558	4·2779	4·1399	4·0297
15	8·6831	6·3589	5·4170	4·8932	4·5556	4·3183	4·1415	4·0045	3·8948
16	8·5310	6·2262	5·2922	4·7726	4·4374	4·2016	4·0259	3·8896	3·7804
17	8·3997	6·1121	5·1850	4·6690	4·3359	4·1015	3·9267	3·7910	3·6822
18	8·2854	6·0129	5·0919	4·5790	4·2479	4·0146	3·8406	3·7054	3·5971
19	8·1850	5·9259	5·0103	4·5003	4·1708	3·9386	3·7653	3·6305	3·5225
20	8·0960	5·8489	4·9382	4·4307	4·1027	3·8714	3·6987	3·5644	3·4567
21	8·0166	5·7804	4·8740	4·3688	4·0421	3·8117	3·6396	3·5056	3·3981
22	7·9454	5·7190	4·8166	4·3134	3·9880	3·7583	3·5867	3·4530	3·3458
23	7·8811	5·6637	4·7649	4·2635	3·9392	3·7102	3·5390	3·4057	3·2986
24	7·8229	5·6136	4·7181	4·2184	3·8951	3·6667	3·4959	3·3629	3·2560
25	7·7698	5·5680	4·6755	4·1774	3·8550	3·6272	3·4568	3·3239	3·2172
26	7·7213	5·5263	4·6366	4·1400	3·8183	3·5911	3·4210	3·2884	3·1818
27	7·6767	5·4881	4·6009	4·1056	3·7848	3·5580	3·3882	3·2558	3·1494
28	7·6356	5·4529	4·5681	4·0740	3·7539	3·5276	3·3581	3·2259	3·1195
29	7·5976	5·4205	4·5378	4·0449	3·7254	3·4995	3·3302	3·1982	3·0920
30	7·5625	5·3904	4·5097	4·0179	3·6990	3·4735	3·3045	3·1726	3·0665
40	7·3141	5·1785	4·3126	3·8283	3·5138	3·2910	3·1238	2·9930	2·8876
60	7·0771	4·9774	4·1259	3·6491	3·3389	3·1187	2·9530	2·8233	2·7185
120	6·8510	4·7865	3·9493	3·4796	3·1735	2·9559	2·7918	2·6629	2·5586
∞	6·6349	4·6052	3·7816	3·3192	3·0173	2·8020	2·6393	2·5113	2·4073

This table gives the values of F for which $I_F(\nu_1, \nu_2) = 0{\cdot}01$.

TABLE 7.6 (cont.)
F Distribution
1% Level of Significance

ν_2 \ ν_1	10	12	15	20	24	30	40	60	120	∞
1	6055·8	6106·3	6157·3	6208·7	6234·6	6260·7	6286·8	6313·0	6339·4	6366·0
2	99·399	99·416	99·432	99·449	99·458	99·466	99·474	99·483	99·491	99·501
3	27·229	27·052	26·872	26·690	26·598	26·505	26·411	26·316	26·221	26·125
4	14·546	14·374	14·198	14·020	13·929	13·838	13·745	13·652	13·558	13·463
5	10·051	9·8883	9·7222	9·5527	9·4665	9·3793	9·2912	9·2020	9·1118	9·0204
6	7·8741	7·7183	7·5590	7·3958	7·3127	7·2285	7·1432	7·0568	6·9690	6·8801
7	6·6201	6·4691	6·3143	6·1554	6·0743	5·9921	5·9084	5·8236	5·7372	5·6495
8	5·8143	5·6668	5·5151	5·3591	5·2793	5·1981	5·1156	5·0316	4·9460	4·8588
9	5·2565	5·1114	4·9621	4·8080	4·7290	4·6486	4·5667	4·4831	4·3978	4·3105
10	4·8492	4·7059	4·5582	4·4054	4·3269	4·2469	4·1653	4·0819	3·9965	3·9090
11	4·5393	4·3974	4·2509	4·0990	4·0209	3·9411	3·8596	3·7761	3·6904	3·6025
12	4·2961	4·1553	4·0096	3·8584	3·7805	3·7008	3·6192	3·5355	3·4494	3·3608
13	4·1003	3·9603	3·8154	3·6646	3·5868	3·5070	3·4253	3·3413	3·2548	3·1654
14	3·9394	3·8001	3·6557	3·5052	3·4274	3·3476	3·2656	3·1813	3·0942	3·0040
15	3·8049	3·6662	3·5222	3·3719	3·2940	3·2141	3·1319	3·0471	2·9595	2·8684
16	3·6909	3·5527	3·4089	3·2588	3·1808	3·1007	3·0182	2·9330	2·8447	2·7528
17	3·5931	3·4552	3·3117	3·1615	3·0835	3·0032	2·9205	2·8348	2·7459	2·6530
18	3·5082	3·3706	3·2273	3·0771	2·9990	2·9185	2·8354	2·7493	2·6597	2·5660
19	3·4338	3·2965	3·1533	3·0031	2·9249	2·8442	2·7608	2·6742	2·5839	2·4893
20	3·3682	3·2311	3·0880	2·9377	2·8594	2·7785	2·6947	2·6077	2·5168	2·4212
21	3·3098	3·1729	3·0299	2·8796	2·8011	2·7200	2·6359	2·5484	2·4568	2·3603
22	3·2576	3·1209	2·9780	2·8274	2·7488	2·6675	2·5831	2·4951	2·4029	2·3055
23	3·2106	3·0740	2·9311	2·7805	2·7017	2·6202	2·5355	2·4471	2·3542	2·2559
24	3·1681	3·0316	2·8887	2·7380	2·6591	2·5773	2·4923	2·4035	2·3099	2·2107
25	3·1294	2·9931	2·8502	2·6993	2·6203	2·5383	2·4530	2·3637	2·2695	2·1694
26	3·0941	2·9579	2·8150	2·6640	2·5848	2·5026	2·4170	2·3273	2·2325	2·1315
27	3·0618	2·9256	2·7827	2·6316	2·5522	2·4699	2·3840	2·2938	2·1984	2·0965
28	3·0320	2·8959	2·7530	2·6017	2·5223	2·4397	2·3535	2·2629	2·1670	2·0642
29	3·0045	2·8685	2·7256	2·5742	2·4946	2·4118	2·3253	2·2344	2·1378	2·0342
30	2·9791	2·8431	2·7002	2·5487	2·4689	2·3860	2·2992	2·2079	2·1107	2·0062
40	2·8005	2·6648	2·5216	2·3689	2·2880	2·2034	2·1142	2·0194	1·9172	1·8047
60	2·6318	2·4961	2·3523	2·1978	2·1154	2·0285	1·9360	1·8363	1·7263	1·6006
120	2·4721	2·3363	2·1915	2·0346	1·9500	1·8600	1·7628	1·6557	1·5330	1·3805
∞	2·3209	2·1848	2·0385	1·8783	1·7908	1·6964	1·5923	1·4730	1·3246	1·0000

$$F = \frac{s_1^2}{s_2^2} = \frac{\nu_2 S_1}{\nu_1 S_2}.$$

TABLE 7.7
Critical Values (Q Values) for Duncan's New Multiple Range Test
5% Level of Significance

ν p	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.07	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97
2	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085
3	4.501	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516
4	3.927	4.013	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033
5	3.635	3.749	3.797	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814
6	3.461	3.587	3.649	3.680	3.694	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697
7	3.344	3.477	3.548	3.588	3.611	3.622	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626
8	3.261	3.399	3.475	3.521	3.549	3.566	3.575	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579
9	3.199	3.339	3.420	3.470	3.502	3.523	3.536	3.544	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547
10	3.151	3.293	3.376	3.430	3.465	3.489	3.505	3.516	3.522	3.525	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526
11	3.113	3.256	3.342	3.397	3.435	3.462	3.480	3.493	3.501	3.506	3.509	3.510	3.510	3.510	3.510	3.510	3.510	3.510
12	3.082	3.225	3.313	3.370	3.410	3.439	3.459	3.474	3.484	3.491	3.496	3.498	3.499	3.499	3.499	3.499	3.499	3.499
13	3.055	3.200	3.289	3.348	3.389	3.419	3.442	3.458	3.470	3.478	3.484	3.488	3.490	3.490	3.490	3.490	3.490	3.490
14	3.033	3.178	3.268	3.329	3.372	3.403	3.426	3.444	3.457	3.467	3.474	3.479	3.482	3.484	3.484	3.485	3.485	3.485
15	3.014	3.160	3.250	3.312	3.356	3.389	3.413	3.432	3.446	3.457	3.465	3.471	3.476	3.478	3.480	3.481	3.481	3.481
16	2.998	3.144	3.235	3.298	3.343	3.376	3.402	3.422	3.437	3.449	3.458	3.465	3.470	3.473	3.477	3.478	3.478	3.478
17	2.984	3.130	3.222	3.285	3.331	3.366	3.392	3.412	3.429	3.441	3.451	3.459	3.465	3.469	3.473	3.475	3.476	3.476
18	2.971	3.118	3.210	3.274	3.321	3.356	3.383	3.405	3.421	3.435	3.445	3.454	3.460	3.465	3.470	3.472	3.474	3.474
19	2.960	3.107	3.199	3.264	3.311	3.347	3.375	3.397	3.415	3.429	3.440	3.449	3.456	3.462	3.467	3.470	3.472	3.473
20	2.950	3.097	3.190	3.255	3.303	3.339	3.368	3.391	3.409	3.424	3.436	3.445	3.453	3.459	3.464	3.467	3.470	3.472
24	2.919	3.066	3.160	3.226	3.276	3.315	3.345	3.370	3.390	3.406	3.420	3.432	3.441	3.449	3.456	3.461	3.465	3.469
30	2.888	3.035	3.131	3.199	3.250	3.290	3.322	3.349	3.371	3.389	3.405	3.418	3.430	3.439	3.447	3.454	3.460	3.466
40	2.858	3.006	3.102	3.171	3.224	3.266	3.300	3.328	3.352	3.373	3.390	3.405	3.418	3.429	3.439	3.448	3.456	3.463
60	2.829	2.976	3.073	3.143	3.198	3.241	3.277	3.307	3.333	3.355	3.374	3.391	3.406	3.419	3.431	3.442	3.451	3.460
120	2.800	2.947	3.045	3.116	3.172	3.217	3.254	3.287	3.314	3.337	3.359	3.377	3.394	3.409	3.423	3.435	3.446	3.457
∞	2.772	2.918	3.017	3.089	3.146	3.193	3.232	3.265	3.294	3.320	3.343	3.363	3.382	3.399	3.414	3.428	3.442	3.454

ν = df(Error)

p = number of means within range being compared

TABLE 7.7 (cont.)
Critical Values (Q Values) for Duncan's New Multiple Range Test
5% Level of Significance

r	p	20	22	24	26	28	30	32	34	36	38	40	50	60	70	80	90	100
1		17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.97	17.07	17.97	17.97	17.97	17.97	17.97
2		6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085	6.085
3		4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516	4.516
4		4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033	4.033
5		3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814	3.814
6		3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.697	3.097	3.697
7		3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.626	3.636	3.626	3.626	3.626	3.626
8		3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579	3.579
9		3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.547	3.574	3.547	3.547
10		3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526	3.526
11		3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510	3.510
12		3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499	3.499
13		3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490	3.490
14		3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485	3.485
15		3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481	3.481
16		3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478	3.478
17		3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476	3.476
18		3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474
19		3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474
20		3.473	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474	3.474
24		3.471	3.475	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477	3.477
30		3.470	3.477	3.481	3.484	3.486	3.486	3.486	3.486	3.486	3.486	3.486	3.486	3.486	3.486	3.486	3.486	3.486
40		3.469	3.479	3.486	3.492	3.497	3.500	3.503	3.504	3.504	3.504	3.504	3.504	3.504	3.504	3.504	3.504	3.504
60		3.467	3.481	3.492	3.501	3.509	3.515	3.521	3.525	3.529	3.531	3.534	3.537	3.537	3.537	3.537	3.537	3.537
120		3.466	3.483	3.498	3.511	3.522	3.532	3.541	3.548	3.555	3.561	3.566	3.585	3.596	3.600	3.601	3.601	3.601
∞		3.466	3.486	3.505	3.522	3.536	3.550	3.562	3.574	3.584	3.594	3.603	3.640	3.668	3.690	3.708	3.722	3.735

TABLE 7.8
Critical Values (Q Values) for Duncan's New Multiple Range Test
1% Level of Significance

v p	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03
2	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04
3	8.261	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321
4	6.512	6.677	6.740	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756
5	5.702	5.893	5.989	6.040	6.065	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074
6	5.243	5.439	5.549	5.614	5.655	5.680	5.694	5.701	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703
7	4.949	5.145	5.260	5.334	5.383	5.416	5.439	5.454	5.464	5.470	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472
8	4.746	4.939	5.057	5.135	5.189	5.227	5.256	5.276	5.291	5.302	5.309	5.314	5.316	5.317	5.317	5.317	5.317	5.317
9	4.596	4.787	4.906	4.986	5.043	5.086	5.118	5.142	5.160	5.174	5.185	5.193	5.199	5.203	5.205	5.206	5.206	5.206
10	4.482	4.671	4.790	4.871	4.931	4.975	5.010	5.037	5.058	5.074	5.088	5.098	5.106	5.112	5.117	5.120	5.122	5.124
11	4.392	4.579	4.697	4.780	4.841	4.887	4.924	4.952	4.975	4.994	5.009	5.021	5.031	5.039	5.045	5.050	5.054	5.057
12	4.320	4.504	4.622	4.706	4.767	4.815	4.852	4.883	4.907	4.927	4.944	4.958	4.969	4.978	4.986	4.993	4.998	5.002
13	4.260	4.442	4.560	4.644	4.706	4.755	4.793	4.824	4.850	4.872	4.889	4.901	4.917	4.928	4.937	4.944	4.950	4.956
14	4.210	4.391	4.508	4.591	4.654	4.704	4.743	4.775	4.802	4.824	4.843	4.859	4.872	4.884	4.894	4.902	4.910	4.916
15	4.168	4.347	4.463	4.547	4.610	4.660	4.700	4.733	4.760	4.783	4.803	4.820	4.834	4.846	4.857	4.868	4.874	4.881
16	4.131	4.309	4.425	4.509	4.572	4.622	4.663	4.696	4.724	4.748	4.768	4.786	4.800	4.813	4.825	4.835	4.844	4.851
17	4.099	4.275	4.391	4.475	4.539	4.589	4.630	4.664	4.693	4.717	4.738	4.756	4.771	4.785	4.797	4.807	4.816	4.824
18	4.071	4.246	4.362	4.445	4.509	4.560	4.601	4.635	4.664	4.689	4.711	4.729	4.745	4.759	4.772	4.783	4.792	4.801
19	4.046	4.220	4.335	4.419	4.483	4.534	4.575	4.610	4.639	4.665	4.686	4.705	4.722	4.736	4.749	4.761	4.771	4.780
20	4.024	4.197	4.312	4.395	4.459	4.510	4.552	4.587	4.617	4.642	4.664	4.684	4.701	4.716	4.729	4.741	4.751	4.761
24	3.956	4.126	4.239	4.322	4.386	4.437	4.480	4.516	4.546	4.573	4.596	4.616	4.634	4.651	4.665	4.678	4.690	4.700
30	3.889	4.056	4.168	4.250	4.314	4.366	4.409	4.445	4.477	4.504	4.528	4.550	4.569	4.586	4.601	4.615	4.628	4.640
40	3.825	3.988	4.098	4.180	4.244	4.296	4.339	4.376	4.408	4.436	4.461	4.483	4.503	4.521	4.537	4.553	4.566	4.579
60	3.762	3.922	4.031	4.111	4.174	4.226	4.270	4.307	4.340	4.368	4.394	4.417	4.438	4.456	4.474	4.490	4.504	4.518
120	3.702	3.858	3.965	4.044	4.107	4.158	4.202	4.239	4.272	4.301	4.327	4.351	4.372	4.392	4.410	4.426	4.412	4.456
∞	3.643	3.796	3.900	3.978	4.040	4.091	4.135	4.172	4.205	4.235	4.261	4.285	4.307	4.327	4.345	4.363	4.379	4.394

v = dF(Error)

p = number of means within range being compared

TABLE 7.8 (cont.)
Critical Values (Q Values) for Duncan's New Multiple Range Test
1% Level of Significance

n	p	20	22	24	26	28	30	32	34	36	38	40	50	60	70	80	90	100
1		90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03	90.03
2		14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04
3		8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321	8.321
4		6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756	6.756
5		6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074	6.074
6		5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703	5.703
7		5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472	5.472
8		5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317	5.317
9		5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206	5.206
10		5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.124	5.121	5.124	5.124	5.124
11		5.059	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061	5.061
12		5.006	5.010	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011	5.011
13		4.960	4.966	4.970	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972	4.972
14		4.921	4.929	4.935	4.938	4.940	4.940	4.940	4.940	4.940	4.940	4.940	4.940	4.940	4.940	4.940	4.940	4.940
15		4.887	4.897	4.904	4.909	4.912	4.914	4.914	4.914	4.914	4.914	4.914	4.914	4.914	4.914	4.914	4.914	4.914
16		4.858	4.869	4.877	4.883	4.887	4.890	4.892	4.892	4.892	4.892	4.892	4.892	4.892	4.892	4.892	4.892	4.892
17		4.832	4.844	4.853	4.860	4.865	4.869	4.872	4.873	4.874	4.874	4.874	4.871	4.874	4.874	4.874	4.874	4.874
18		4.808	4.821	4.832	4.839	4.846	4.850	4.854	4.856	4.857	4.858	4.858	4.858	4.858	4.858	4.858	4.858	4.858
19		4.788	4.802	4.812	4.821	4.828	4.833	4.838	4.841	4.843	4.844	4.845	4.845	4.845	4.845	4.845	4.845	4.845
20		4.769	4.784	4.795	4.805	4.813	4.818	4.823	4.827	4.830	4.832	4.833	4.833	4.833	4.833	4.833	4.833	4.833
24		4.710	4.727	4.741	4.752	4.762	4.770	4.777	4.783	4.788	4.791	4.794	4.802	4.802	4.802	4.802	4.802	4.802
30		4.650	4.669	4.685	4.699	4.711	4.721	4.730	4.738	4.744	4.750	4.755	4.772	4.777	4.777	4.777	4.777	4.777
40		4.591	4.611	4.630	4.645	4.659	4.671	4.682	4.692	4.700	4.708	4.715	4.740	4.754	4.761	4.764	4.764	4.764
60		4.530	4.553	4.573	4.591	4.607	4.620	4.633	4.645	4.655	4.665	4.673	4.707	4.730	4.745	4.755	4.761	4.765
120		4.469	4.494	4.516	4.535	4.552	4.568	4.583	4.596	4.609	4.619	4.630	4.673	4.703	4.727	4.745	4.759	4.770
∞		4.408	4.434	4.457	4.478	4.497	4.514	4.530	4.545	4.559	4.572	4.584	4.635	4.675	4.707	4.734	4.756	4.776

TABLE 7.9
One-Tailed Binomial Test
Probability of X or more correct judgements in n trials (p=1/3)

n \ X	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
5		868	539	210	045	004																							
6		912	649	320	100	018	001																						
7		941	737	429	173	045	007																						
8		961	805	532	259	088	020	003																					
9		974	857	623	350	145	042	008	001																				
10		983	896	701	441	213	077	020	003																				
11		988	925	766	527	289	122	039	009	001																			
12		992	946	819	607	368	178	066	019	004	001																		
13		995	961	861	678	448	241	104	035	009	002																		
14		997	973	895	739	524	310	149	058	017	004	001																	
15		998	981	921	791	596	382	203	088	031	008	002																	
16		998	986	941	834	661	453	263	126	050	016	004	001																
17		999	990	956	870	719	522	326	172	075	027	008	002																
18		999	993	967	898	769	588	391	223	108	043	014	004	001															
19			995	976	921	812	648	457	279	146	065	024	007	002															
20			997	982	940	848	703	521	339	191	092	038	013	004	001														
21			998	987	954	879	751	581	399	240	125	056	021	007	002														
22			998	991	965	904	794	638	460	293	163	079	033	012	003	001													
23			999	993	974	924	831	690	519	349	206	107	048	019	006	002													
24			999	995	980	941	862	737	576	406	254	140	068	028	010	003	001												
25			999	996	985	954	888	778	630	462	304	178	092	042	016	006	002												
26				997	989	964	910	815	679	518	357	220	121	058	025	009	003	001											
27				998	992	972	928	847	725	572	411	266	154	079	036	014	005	002											
28				999	994	979	943	874	765	623	464	314	191	104	060	022	008	003	001										
29				999	996	984	955	897	801	670	517	364	232	133	068	031	013	005	001										
30				999	997	988	965	916	833	714	568	415	276	166	090	043	019	007	002	001									
31					998	991	972	932	861	754	617	466	322	203	115	059	027	011	004	001									
32					998	993	978	946	885	789	662	516	370	243	144	078	038	016	006	002	001								
33					999	995	983	957	905	821	705	565	419	285	177	100	051	023	010	004	001								
34					999	996	987	965	922	849	744	612	468	330	213	126	067	033	014	006	002	001							
35					999	997	990	973	937	873	779	656	516	376	252	155	087	044	020	009	003	001							
36						998	992	978	949	895	810	697	562	422	293	187	109	058	028	012	005	002	001						
37						998	994	963	959	913	838	735	607	469	336	223	135	075	038	018	007	003	001						
38						999	996	987	967	928	863	769	650	515	381	261	164	095	051	025	011	004	002	001					
39						999	997	990	973	941	885	800	689	560	425	301	196	118	066	033	016	007	003	001					
40						999	997	992	979	952	903	829	726	603	470	342	231	144	083	044	021	010	004	001					
41							998	994	983	961	920	854	761	644	515	385	268	173	104	067	029	014	006	002	001				
42							999	996	987	968	933	876	791	683	558	428	307	205	127	073	038	019	008	003	001				
43							999	996	990	974	945	895	820	719	600	471	347	239	153	091	050	025	012	005	002	001			
44							999	997	992	980	955	912	845	753	639	514	389	275	182	111	063	033	016	007	003	001			
45							999	998	994	984	963	926	867	783	677	556	430	313	213	135	079	043	022	010	004	002	001		
46								998	995	987	970	938	887	811	713	596	472	352	246	161	098	055	029	014	006	003	001		
47								999	996	990	976	949	904	836	746	635	514	392	282	189	119	070	038	019	009	004	002	001	
48								999	997	992	980	958	919	859	776	672	554	433	318	220	142	086	048	025	012	006	002	001	
49								999	998	994	984	965	932	879	803	706	593	473	356	253	168	105	061	033	017	008	003	001	
50								999	998	995	987	972	943	896	829	739	631	513	395	287	196	126	076	042	022	011	005	002	001

* NOTE Initial decimal point has been omitted

TABLE 7.10
Percentage Points of the Studentized Range
Upper 5% Points

ν \ n	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	18·0	27·0	32·8	37·1	40·4	43·1	45·4	47·4	49·1	50·6	52·0	53·2	54·3	55·4	56·3	57·2	58·0	58·8	59·6
2	6·09	8·3	9·8	10·9	11·7	12·4	13·0	13·5	14·0	14·4	14·7	15·1	15·4	15·7	15·9	16·1	16·4	16·6	16·8
3	4·50	5·91	6·82	7·50	8·04	8·48	8·85	9·18	9·46	9·72	9·95	10·15	10·35	10·52	10·69	10·84	10·98	11·11	11·24
4	3·93	5·04	5·76	6·29	6·71	7·05	7·35	7·60	7·83	8·03	8·21	8·37	8·52	8·66	8·79	8·91	9·03	9·13	9·23
5	3·64	4·60	5·22	5·67	6·03	6·33	6·58	6·80	6·99	7·17	7·32	7·47	7·60	7·72	7·83	7·93	8·03	8·12	8·21
6	3·46	4·34	4·90	5·31	5·63	5·89	6·12	6·32	6·49	6·65	6·79	6·92	7·03	7·14	7·24	7·34	7·43	7·51	7·59
7	3·34	4·16	4·68	5·06	5·36	5·61	5·82	6·00	6·16	6·30	6·43	6·55	6·66	6·76	6·85	6·94	7·02	7·09	7·17
8	3·26	4·04	4·53	4·89	5·17	5·40	5·60	5·77	5·92	6·05	6·18	6·29	6·39	6·48	6·57	6·65	6·73	6·80	6·87
9	3·20	3·95	4·42	4·76	5·02	5·24	5·43	5·60	5·74	5·87	5·98	6·09	6·19	6·28	6·36	6·44	6·51	6·58	6·64
10	3·15	3·88	4·33	4·65	4·91	5·12	5·30	5·46	5·60	5·72	5·83	5·93	6·03	6·11	6·20	6·27	6·34	6·40	6·47
11	3·11	3·82	4·26	4·57	4·82	5·03	5·20	5·35	5·49	5·61	5·71	5·81	5·90	5·99	6·06	6·14	6·20	6·26	6·33
12	3·08	3·77	4·20	4·51	4·75	4·95	5·12	5·27	5·40	5·51	5·62	5·71	5·80	5·88	5·95	6·03	6·09	6·15	6·21
13	3·06	3·73	4·15	4·45	4·69	4·88	5·05	5·19	5·32	5·43	5·53	5·63	5·71	5·79	5·86	5·93	6·00	6·05	6·11
14	3·03	3·70	4·11	4·41	4·64	4·83	4·99	5·13	5·25	5·36	5·46	5·55	5·64	5·72	5·79	5·85	5·92	5·97	6·03
15	3·01	3·67	4·08	4·37	4·60	4·78	4·94	5·08	5·20	5·31	5·40	5·49	5·58	5·65	5·72	5·79	5·85	5·90	5·96
16	3·00	3·65	4·05	4·33	4·56	4·74	4·90	5·03	5·15	5·26	5·35	5·44	5·52	5·59	5·66	5·72	5·79	5·84	5·90
17	2·98	3·63	4·02	4·30	4·52	4·71	4·86	4·99	5·11	5·21	5·31	5·39	5·47	5·55	5·61	5·68	5·74	5·79	5·84
18	2·97	3·61	4·00	4·28	4·49	4·67	4·82	4·96	5·07	5·17	5·27	5·35	5·43	5·50	5·57	5·63	5·69	5·74	5·79
19	2·96	3·59	3·98	4·25	4·47	4·65	4·79	4·92	5·04	5·14	5·23	5·32	5·39	5·46	5·53	5·59	5·65	5·70	5·75
20	2·95	3·58	3·96	4·23	4·45	4·62	4·77	4·90	5·01	5·11	5·20	5·28	5·36	5·43	5·49	5·55	5·61	5·66	5·71
24	2·92	3·53	3·90	4·17	4·37	4·54	4·68	4·81	4·92	5·01	5·10	5·18	5·25	5·32	5·38	5·44	5·50	5·54	5·59
30	2·89	3·49	3·84	4·10	4·30	4·46	4·60	4·72	4·83	4·92	5·00	5·08	5·15	5·21	5·27	5·33	5·38	5·43	5·48
40	2·86	3·44	3·79	4·04	4·23	4·39	4·52	4·63	4·74	4·82	4·91	4·98	5·05	5·11	5·16	5·22	5·27	5·31	5·36
60	2·83	3·40	3·74	3·98	4·16	4·31	4·44	4·55	4·65	4·73	4·81	4·88	4·94	5·00	5·06	5·11	5·16	5·20	5·24
120	2·80	3·36	3·69	3·92	4·10	4·24	4·36	4·48	4·56	4·64	4·72	4·78	4·84	4·90	4·95	5·00	5·05	5·09	5·13
∞	2·77	3·31	3·63	3·86	4·03	4·17	4·29	4·39	4·47	4·55	4·62	4·68	4·74	4·80	4·85	4·89	4·93	4·97	5·01

n is the size of sample from which the range is obtained and ν is the number of degrees of freedom of s_ν.

TABLE 7.11

Percentage Points of the Studentized Range

Upper 1% Points

ν \ n	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	90·0	135	164	186	202	216	227	237	246	253	260	266	272	277	282	286	290	294	298
2	14·0	19·0	22·3	24·7	26·6	28·2	29·5	30·7	31·7	32·6	33·4	34·1	34·8	35·4	36·0	36·5	37·0	37·5	37·9
3	8·26	10·6	12·2	13·3	14·2	15·0	15·6	16·2	16·7	17·1	17·5	17·9	18·2	18·5	18·8	19·1	19·3	19·5	19·8
4	6·51	8·12	9·17	9·96	10·6	11·1	11·5	11·9	12·3	12·6	12·8	13·1	13·3	13·5	13·7	13·9	14·1	14·2	14·4
5	5·70	6·97	7·80	8·42	8·91	9·32	9·67	9·97	10·24	10·48	10·70	10·89	11·08	11·24	11·40	11·55	11·68	11·81	11·93
6	5·24	6·33	7·03	7·56	7·97	8·32	8·61	8·87	9·10	9·30	9·49	9·65	9·81	9·95	10·08	10·21	10·32	10·43	10·54
7	4·95	5·92	6·54	7·01	7·37	7·68	7·94	8·17	8·37	8·55	8·71	8·86	9·00	9·12	9·24	9·35	9·46	9·55	9·65
8	4·74	5·63	6·20	6·63	6·96	7·24	7·47	7·68	7·87	8·03	8·18	8·31	8·44	8·55	8·66	8·76	8·85	8·94	9·03
9	4·60	5·43	5·96	6·35	6·66	6·91	7·13	7·32	7·49	7·65	7·78	7·91	8·03	8·13	8·23	8·32	8·41	8·49	8·57
10	4·48	5·27	5·77	6·14	6·43	6·67	6·87	7·05	7·21	7·36	7·48	7·60	7·71	7·81	7·91	7·99	8·07	8·15	8·22
11	4·39	5·14	5·62	5·97	6·25	6·48	6·67	6·84	6·99	7·13	7·25	7·36	7·46	7·56	7·65	7·73	7·81	7·88	7·95
12	4·32	5·04	5·50	5·84	6·10	6·32	6·51	6·67	6·81	6·94	7·06	7·17	7·26	7·36	7·44	7·52	7·59	7·66	7·73
13	4·26	4·96	5·40	5·73	5·98	6·19	6·37	6·53	6·67	6·79	6·90	7·01	7·10	7·19	7·27	7·34	7·42	7·48	7·55
14	4·21	4·89	5·32	5·63	5·88	6·08	6·26	6·41	6·54	6·66	6·77	6·87	6·96	7·05	7·12	7·20	7·27	7·33	7·39
15	4·17	4·83	5·25	5·56	5·80	5·99	6·16	6·31	6·44	6·55	6·66	6·76	6·84	6·93	7·00	7·07	7·14	7·20	7·26
16	4·13	4·78	5·19	5·49	5·72	5·92	6·08	6·22	6·35	6·46	6·56	6·66	6·74	6·82	6·90	6·97	7·03	7·09	7·15
17	4·10	4·74	5·14	5·43	5·66	5·85	6·01	6·15	6·27	6·38	6·48	6·57	6·66	6·73	6·80	6·87	6·94	7·00	7·05
18	4·07	4·70	5·09	5·38	5·60	5·79	5·94	6·08	6·20	6·31	6·41	6·50	6·58	6·65	6·72	6·79	6·85	6·91	6·96
19	4·05	4·67	5·05	5·33	5·55	5·73	5·89	6·02	6·14	6·25	6·34	6·43	6·51	6·58	6·65	6·72	6·78	6·84	6·89
20	4·02	4·64	5·02	5·29	5·51	5·69	5·84	5·97	6·09	6·19	6·29	6·37	6·45	6·52	6·59	6·65	6·71	6·76	6·82
24	3·96	4·54	4·91	5·17	5·37	5·54	5·69	5·81	5·92	6·02	6·11	6·19	6·26	6·33	6·39	6·45	6·51	6·56	6·61
30	3·89	4·45	4·80	5·05	5·24	5·40	5·54	5·65	5·76	5·85	5·93	6·01	6·08	6·14	6·20	6·26	6·31	6·36	6·41
40	3·82	4·37	4·70	4·93	5·11	5·27	5·39	5·50	5·60	5·69	5·77	5·84	5·90	5·96	6·02	6·07	6·12	6·17	6·21
60	3·76	4·28	4·60	4·82	4·99	5·13	5·25	5·36	5·45	5·53	5·60	5·67	5·73	5·79	5·84	5·89	5·93	5·98	6·02
120	3·70	4·20	4·50	4·71	4·87	5·01	5·12	5·21	5·30	5·38	5·44	5·51	5·56	5·61	5·66	5·71	5·75	5·79	5·83
∞	3·64	4·12	4·40	4·60	4·76	4·88	4·99	5·08	5·16	5·23	5·29	5·35	5·40	5·45	5·49	5·54	5·57	5·61	5·65

n is the size of the sample from which the range is obtained and ν is the number of degrees of freedom of s_{ν}.

REFERENCES

REFERENCES CITED

Amerine, M.A., Pangborn, R.M. and Roessler, E.B. 1965. "Principles of Sensory Evaluation of Food." Academic Press, New York.

ASTM Committee E-18, 1986. Physical requirement guidelines for sensory evaluation laboratories. STP 913. Am. Soc. for Testing and Materials, Philadelphia, Pa.

ASTM Committee E-18, 1981. Guidelines for the selection and training of sensory panel members. STP 758. Am. Soc. for Testing and Materials, Philadelphia, Pa.

ASTM Committee E-18, 1979. Manual on consumer sensory evaluation. STP 682. Am. Soc. for Testing and Materials, Philadelphia, Pa.

ASTM Committee E-18, 1968. Manual on sensory testing methods. STP 434. Am. Soc. for Testing and Materials, Philadelphia, Pa.

ASTM Committee E-18, 1968. Basic principles of sensory evaluation. STP 433. Am. Soc. for Testing and Materials, Philadelphia, Pa.

Basker, D. 1988. Critical values of differences among rank sums for multiple comparisons. *Food Technol.* 42(2):79.

Brandt, M.A., Skinner, E.Z. and Coleman, J.A. 1963. Texture profile method. *J. Food Sci.* 28:404.

Cairncross, S.E. and Sjostrom, L.B. 1950. Flavor profiles - A new approach to flavor problems. *Food Technol.* 4(8):308.

Cardello, A.V. and Maller, O. 1982 Relationships between food preferences and food acceptance ratings. *J. Food Sci.* 47:1553.

Caul, J.F. 1957. The profile method of flavor analysis. *Adv. Food Research* 7:1.

Civille, G.V. and Szczesniak, A.S. 1973. Guidelines to training a texture profile panel. *J. Texture Studies* 4:204.

Daget, N. 1977. Sensory evaluation or sensory measurement? In "Nestle Research News 1976/77". C. Boella (Ed.). Nestle Products Technical Assistance Co. Ltd., Switzerland.

Ennis, D.M., Boelens, H., Haring, H. and Bowman, P. 1982. Multivariate analysis in sensory evaluation. *Food Technol.* 36(11):83.

Gacula, M.C. Jr. and Singh, J. 1984. "Statistical Methods in Food and Consumer Research." Academic Press, Inc., New York.

IFT Sensory Evaluation Division. 1981. Sensory evaluation guide for testing food and beverage products. *Food Technol.* 35(11):50.

Jellinek, G. 1985. "Sensory Evaluation of Food. Theory and Practice." Ellis Horwood, Chichester, England.

Joanes, D.N. 1985. On a rank sum test due to Kramer. *J. Food Sci.* 50:1442.

Larmond, E. 1977. "Laboratory Methods for Sensory Evaluation of Food." Research Branch, Canada Department of Agriculture, Ottawa. Publication 1637.

McPherson, R.S. and Randall, E. 1985. Line length measurement as a tool for food preference research. *Ecol. Food Nutr.* 17(2):149.

Meilgaard, M. C., Civille, G.V. and Carr, B.T. 1987. "Sensory Evaluation Techniques," Vols. I and II. CRC Press, Inc., Boca Raton, Florida.

Moskowitz, H.R. 1983. "Product Testing and Sensory Evaluation of Foods, Marketing and R & D Approaches." Food and Nutrition Press, Inc., Westport, Connecticut.

Newell, G.J. and MacFarlane, J.D. 1987. Expanded tables for multiple comparison procedures in the analysis of ranked data. *J. Food Sci.* 52:1721.

O'Mahony, M. 1986. "Sensory Evaluation of Food. Statistical Methods and Procedures." Marcel Dekker, Inc., New York, N.Y.

O'Mahony, M. 1982. Some assumptions and difficulties with common statistics for sensory analysis. Food Technol. 36(11):75.

Pangborn, R.M.V. 1986. Sensory techniques of food analysis. In "Food Analysis Principles and Techniques. Vol. 1. Physical Characterization," D.W. Gruenwedel and J.R. Whitaker, (Ed.). Marcel Dekker, Inc., New York, N.Y.

Piggott, J.R. (Ed.), 1984. "Sensory Analysis of Foods." Elsevier Applied Science Publishers, London, England.

Powers, J.J. 1984. Using general statistical programs to evaluate sensory data. *Food Technol.* 38(6):74.

Powers, J.J. 1981. Multivariate procedures in sensory research: scope and limitations. MBAA Technical Quarterly 18(1):11.

Snedecor, G.W. and Cochran, W.G. 1980. "Statistical Methods," 7th ed. Iowa State University Press, Ames, Iowa.

Steel, R.G.D. and Torrie, J.H. 1980. "Principles and Procedures of Statistics," 2nd ed, McGraw-Hill, New York, N.Y.

Stone, H. and Sidel, J.L. 1985. "Sensory Evaluation Practices." Academic Press, Inc., New York, N.Y.

Stone, H., Sidel, J.L. and Bloomquist, J. 1980. Quantitative descriptive analysis. Cereal Foods World 25(10):642.

Stone, H., Sidel, J.L., Oliver, S., Woolsey, A. and Singleton, R.C. 1974. Senso ry evaluation by quantitative descriptive analysis. *Food Technol.* 28(11):24.

Stungis, G.E. 1976. Overview of applied multivariate analysis. In "Correlating Sensory Objective Measurements - New Methods for Answering Old Problems". ASTM STP 594, Am. Soc. for Testing and Materials, Philadelphia, Pa.

Szczesniak, A.S. 1963. Classification of textural characteristics. *J. Food Sci.* 28:385.

Szczesniak, A.S., Brandt, M.A. and Friedman, H.H. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. *J. Food Sci.* 28:397.

Zook, K. and Wessman, C. 1977. The selection and use of judges for descriptive panels. *Food Technol.* 31(11):56.

ADDITIONAL REFERENCES

AMSA. 1978. Guidelines for cookery and sensory evaluation of meat. American Meat Science Association and National Live Stock and Meat Board.

Bieber, S.L. and Smith, D.V. 1986. Multivariate analysis of sensory data: A comparison of methods. *Chemical Senses* 11(1):19.

Bourne, M.C. 1978. Texture profile analysis. *Food Technol.* 32(7):62.

Cardello, A.V., Maller, O., Kapsalis, J.G., Segars, R.A., Sawyer, F.M., Murphy, C. and Moskowitz, H.R. 1982. Perception of texture by trained and consumer panelists. *J. Food Sci.* 47:1186.

Civille, G.V. 1978. Case studies demonstrating the role of sensory evaluation in product developments. *Food Technol.* 32(11):59.

Cross, H.R., Moen, R. and Stanfield, M.S. 1978. Training and testing of judges for sensory analysis of meat quality. *Food Technol.* 32(7):48.

Gatchalian, M.M. 1981. "Sensory Evaluation Methods with Statistical Analysis." College of Home Economics, University of the Philippines, Diliman, Philippines.

Larmond, E. 1973. Physical requirements for sensory testing. *Food Technol.* 27(11):28.

Moskowitz, H.R. 1978. Magnitude estimation: notes on how, what, where and why to use it. *J. Food Quality* 1:195.

Moskowitz, H.R. 1974. Sensory evaluation by magnitude estimation. *Food Technol.* 28(11):16.

Roessler, E.B., Pangborn, R.M., Sidel, J.L. and Stone, H. 1978. Expanded statistical tables for estimating significance in paired-preference, paired difference, duo-trio and triangle tests. *J. Food Sci.* 43:940.

Sidel, J.L. and Moskowitz, H.R. 1971. Magnitude and hedonic scales of food acceptability. *J. Food Sci.* 36:677.

Sidel, J.L. and Stone, H. 1976. Experimental design and analysis of sensory tests. *Food Technol.* 30(11):32.

Sidel, J.L., Stone, H. and Bloomquist, J. 1981. Use and misuse of sensory evaluation in research and quality control. *J. Dairy Sci.* 64:2296.

Szczesniak, A.S., Lowe, B.J. and Skinner, E.L. 1975. Consumer textural profile technique. *J. Food Sci.* 40:1253.

Wolfe, K.A. 1979. Use of reference standards for sensory evaluation of product quality. *Food Technol.* 33(9):43.

GLOSSARY

Explanations and definitions of terms used in this glossary were taken from the following references:

Amerine, M.A., Pangborn, R.M. and Roessler, E.B. 1965. "*Principles of Sensory Evaluation of Food.*" Academic Press, New York, N.Y.

Davies, P. (Ed.) 1970. "*The American Heritage Dictionary of the English Language.*" Dell Publishing Co., Inc. New York, N.Y.

Gacula, M.C. Jr. and Singh, J. 1984. "*Statistical Methods in Food and Consumer Research.*" Academic Press, Inc., Orlando, Florida.

Guralnik, D.B. (Ed.) 1963. "Webster's New World Dictionary." Nelson, Foster & Scott Limited, Toronto.

Hirsh, N.L. 1971. Sensory good sense. *Food Product Devel.* 5(6):27-29.

Huck, S.W., Cormier, W.H. and Bounds, W.G.Jr. 1974. "*Reading Statistics and Research.*" Harper & Row Publishers, New York, N.Y.

IFT Sensory Evaluation Division. 1981. Sensory evaluation guide for testing food and beverage products. *Food Technol.* 35(11):50.

Kramer, A. 1959. Glossary of some terms used in the sensory (panel) evaluation of foods and beverages. *Food Technol.* 13(12):733-736.

Linton, M. and Gallo, P.S.Jr. 1975. "*The Practical Statistician: Simplified Handbook of Statistics.*" Brooks/Cole Publishing Company, California.

Lowry, S.R. 1979. Statistical planning and designing of experiments to detect differences in sensory evaluation of beef loin steaks. *J. Food Sci.* 44:488-491.

O'Mahoney, M. 1986. "*Sensory Evaluation of Food. Statistical Methods and Procedures.*" Marcel Dekker, Inc., New York, N.Y.

Piggott, J.R. (Ed.), 1984. "*Sensory Analysis of Foods.*" Elsevier Applied Science Publishers, London, England.

Terms and Definitions

Acceptability (*n*) - Attitude towards a product, expressed by a consumer, often indicating its actual use (purchase or eating).

Accuracy (*n*) - Closeness with which measurements taken approach the true value; exactness; correctness.

Acuity (*n*) - Fineness of sensory recognition or discrimination; ability to discern or perceive small differences in stimuli; sharpness or acuteness.

Affective Test - A test used to evaluate subjective attitudes such as preference, acceptance and/or degree of liking of foods by untrained panelists.

Aftertaste (*n*) - The experience, which under certain conditions, follows the removal of a taste stimulus.

Ageusia (*n*) - Lack or impairment of sensitivity to taste stimuli.

Analysis of Variance - A mathematical procedure for segregating the sources of variability affecting a set of observations; used to test whether the means of several samples differ in some way or are the same.

Analytical Test - A test used for laboratory evaluation of products by trained panelists in terms of differences or similarities and for identification and quantification of sensory characteristics.

Anosmia (*n*) - Lack or impairment of sensitivity to odour stimuli.

Arbitrary (*adj*) - Based on or subject to personal or individual judgment.

Assess (*v*) - To evaluate.

Attribute (*n*) - A perceived characteristic; a distinctive feature, quality or aspect of a food product.

Ballot (*n*) - A form used by a panelist to record sample scores, decisions, comments; usually includes instructions to the panelist related to the type of test being performed.

Basic Taste - Sweet, sour, salty or bitter sensation.

Batch (*n*) - A definite quantity of some food product chosen from the population of that food, and from which samples are withdrawn.

Bias (*n*) - A prejudiced or influenced judgment.

Binomial Test - A test of the frequency of occurrence in two categories; used when only two possible outcomes are allowed.

Blind Control - A reference sample, whose identity is known only to the researcher, coded and presented with experimental samples.

Category (*n*) - A defined division in a system of classification.

Category Scale - A scale divided into numerical and/or descriptive classifications.

Characteristic (*n*) - Odour, flavour, texture or appearance property of a product.

Chi-Square Test - Non-parametric test used to determine whether a significant difference exists between an observed number and an expected number of responses falling in each category designated by the researcher; used to test hypotheses about the frequency of occurrence in any number of categories.

Classification (*n*) - Category.

Classify (*v*) - To sort into predetermined categories.

Code (*v*) - Assignment of symbols, usually 3-digit random numbers, to samples so that they may be presented to panelists without identification.

Conditional (*adj*) - Implying a condition or prerequisite.

Conservative (*adj*) - Moderate; cautious.

Consistency (*n*) - Agreement or harmony of parts; uniformity.

Consumer (*n*) - An individual who obtains and uses a commodity.

Consumer Panel - A group of individuals representative of a specific population whose behaviour is measured.

Conventional (*adj*) - Approved by or following general usage; customary.

Correlation Analysis - A method to determine the nature and degree of relationship between variables.

Critical Value - A criterion or scientific cut-off point related to the chosen level of significance.

Definition (*n*) - A statement of the meaning of a word, phrase or term; the act of making clear and distinct.

Descriptive Test - A test used to measure the perceived intensity of a sensory property or characteristic.

Difference Test - A test used to determine if two samples are perceptibly different.

Discriminate (*v*) - To perceive or detect a difference between two or more stimuli.

Effect (*n*) - Something brought about by a cause or agent; result.

Efficient (*adj*) - Acting or producing effectively with a minimum of waste or effort.

Expectorate (*v*) - To eject from the mouth; spit.

Experimental Error - Measure of the variation which exists among observations on samples treated alike.

Form (*n*) - A document printed with spaces for information to be inserted.

Frequency (*n*) - The number of responses falling within a specified category or interval.

Hedonic (*adj*) - Degree of liking or disliking.

Hedonic Scale - A scale upon which degree of liking and disliking is recorded.

Hypothesis (*n*) - An expression of the researcher's assumptions or expectations concerning the outcome of his research, subject to verification or proof; may be derived from a theory, may be based on past observations or may merely be a hunch.

Illustrate (*v*) - To clarify by use of example or comparison.

Independent (*adj*) - Free from the influence, guidance or control of others.

Inference (*n*) - Scientific guess about a population based on sample data.

Intensity (*n*) - Perceived strength of a stimulus.

Interaction (*n*) - A measure of the extent to which the effect of changing the level of one factor depends on the level or levels of another or others.

Label (n) - Means of identification. (*v*) - To attach a label to.

Liberal (*adj*) - Tolerant; generous.

Mask (*v*) - Disguise or conceal.

Mean (*n*) - Sum of all the scores divided by the number of scores.

Molar Teeth - Teeth with a broad crown for grinding food, located behind the bicuspids.

Monitor (*v*) - To check, watch or keep track of.

Motivate (*v*) - To provide with an incentive or motive; maintain panel interest and morale.

Noticeable (*adj*) - Readily observed; evident.

Objective (*n*) - Something aimed at; goal.

Odour (*n*) - Characteristic that can be perceived by the olfactory organ.

Orient (*v*) - To familiarize participants with or adjust to a situation.

Palate (*n*) - The roof of the mouth.

Panel (*n*) - A group of assessors who have been selected or designated in some manner to participate in a sensory test.

Panel Leader - A person responsible for organizing, conducting and directing a panel.

Panelist (*n*) - A member of a panel.

Perceive (*v*) - To become aware of a stimuli through the senses.

Perceptible (*adj*) - Capable of being perceived.

Perishable (*adj*) - Easily destroyed or spoiled.

Portion (*n*) - A section or quantity within a larger amount.
(*v*) - To divide into parts.

Precise (*adj*) - Ability of repeated measurements to be identical, or almost identical.

Precision (*n*) - Closeness of repeated measurements to each other.

Preference (*n*) - Expressed choice for a product or products rather than another product or products.

Probability (*n*) - The likelihood or chance of a given event happening.

Psychological Factors - Involving the mind or emotions.

Qualitative (*adj*) - Pertaining to quality; involved in variation in kind rather than in degree.

Quality (*n*) - Degree of excellence.

Quantitative (*adj*) - Pertaining to number or quantity.

Random Sample - Batch or sample chosen such that all members of the population have an equal chance of being selected.

Rank (*v*) - To order a series of three or more samples by the degree of some designated characteristic, such as intensity or acceptability.

Recruit (*v*) - To seek and enroll individuals as participants.

Reference (*n*) - A constant sample with which others are compared or against which descriptive terms are calibrated.

Reliability (*n*) - Extent to which the same characteristic can be measured consistently upon repeated occasions.

Reliable (*adj*) - Measuring what the experimenter expects to measure; dependable.

Replication (*n*) - Independent repetitions of an experiment under identical experimental conditions.

Representative (*adj*) - Typical of others in the same category, group or population. A representative sample of consumers should match the population distribution of users by age, sex, socio-economic group, occupation, etc.

Reproduce (*v*) - To make a copy of or re-create.

Sample (*n*) - A portion, piece or segment regarded as representative of a whole and presented for inspection. (*v*) - To take a sample of.

Scale (n) - A system of ordered marks or divisions at fixed intervals used in measurement, which may be graphic, descriptive or numerical.

Score (*n*) - Values assigned to specific responses made to a test item where the scores have a defined and demonstrated mathematical relationship to each other.

(*v*) - To rate the properties of a product on a scale or according to some numerically defined set of criteria.

Scorecard (*n*) - Card or paper on which samples are scored.

Screen (*v*) - To separate out or eliminate individuals who are completely unsuitable for sensory evaluation by testing for sensory impairment and acuity.

Sense (*n*) - Any of the functions of hearing, sight, smell, touch and taste.

Sensitivity (*n*) - Ability of individuals to detect or perceive quantitative and/or qualitative differences in sensory characteristics; acuity.

Sensory (*adj*) - Pertaining to the action of the sense organs.

Sensory Analysis - A scientific discipline used to evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing.

Sensory Evaluation - See sensory analysis.

Sensory Testing - See sensory analysis.

Significance (n) - Level of probability that the differences among samples or treatments are real and not due to chance variation.

Simultaneously (*adj*) - Happening or done at the same time.

Sniff (*v*) - To evaluate an odour by drawing air audibly and abruptly through the nose.

Stagger (*v*) - To arrange in alternating or overlapping time periods.

Statistics (*n*) - The mathematics of the collection, organization and interpretation of numerical data, particularly the analysis of population characteristics by inference from sampling.

Stimulus (*n*) - Anything causing or regarded as causing a response.

Tactile Senses - Pertaining to the sense of touch.

Tie (*n*) - An equality of scores between two or more samples.

Training (*n*) - Instruction and practice to familiarize panelists with test procedures and to increase their ability to recognize, identify and recall sensory characteristics.

Treatment (*n*) - Procedure whose effect is measured and compared with other treatments.

Trial Run - The process of testing, trying and timing methods and procedures through their actual use.

Valid (*adj*) - Drawing the proper and correct conclusions from the data.

Validity (*n*) - Assurance that the specific characteristic that is supposed to be measured is truly being measured. Degree to which results are consistent with the facts.

INDEX

Acceptability *7, 48, 49, 51*
Acceptance *59, 60, 63*
Affective test *59*
Analysis of variance *34, 55, 68, 70, 72, 91, 94, 99, 115*
Analytical test *59*

Binomial test *55, 61, 82*
Blind control *42*
Blocking *54, 57, 58, 69*

Carriers *40*
Category scale *49, 50, 55, 60, 63, 66, 68, 70, 90*
Chi-square test *55*
Consumer panel *8, 23, 48, 51, 53, 60, 65, 70*
Consumer *7, 8, 9, 51, 60, 63, 70*
Consumer-oriented test *7, 8, 48, 51, 53, 59, 60*
Correlation *56*

Discriminant analysis *56*
Duncan's multiple range test *55, 76, 101*
Duo-trio test *80*

Endpoints *49, 114, 117*
Experimental design *5, 56, 57, 58*
Experimental error *58, 68, 69, 91*

Factor analysis *56*
Flavour profile *104*
Food preparation *7, 11, 12, 13, 14, 17, 19, 23, 26*
Friedman test *55, 65, 87*

Hedonic *60, 66, 68, 70, 75, 94*
Hidden reference *42*
In-house panel *8, 29, 30, 62, 63, 65, 66, 70, 83*

Kramer test *55*

Least significant difference test *55*
Line scale *49, 50, 90, 91, 92, 114*

Monitoring performance *14, 29, 32, 33, 34, 35, 41, 54, 114, 115*
Motivating panelists *29, 35*
Multiple comparison test *55, 76, 100, 101*
Multivariate analysis *56, 91*

Non-parametric test *54, 55*

Objectives *47, 56, 105, 106*
Orienting panelists *30, 106*

Paired-comparison test *80*
Paired-preference test *60, 61, 62, 63, 80, 82*
Panel leader *11, 13, 17, 18, 25, 26, 29, 30, 32, 33, 34, 35, 48, 111, 114*
Parametric test *54, 55*
Preference *7, 8, 32, 48, 49, 51, 59, 60, 61, 62*
Principal component analysis *56*
Probability *52, 53, 61, 62, 78, 82, 83, 85, 103*
Product-oriented test *7, 8, 9, 13, 48, 49, 51, 53, 59, 79*

Quantitative descriptive analysis *104*
Questionnaire *30*

Random number *44, 57, 68, 81, 90*
Random sample *8, 53*
Randomization *44, 57, 68, 106*
Recruiting panelists *29, 30, 106*
Reference sample *13, 37, 41, 42, 80, 114*
Regression *56*
Replication *54, 57, 58, 91, 92, 94, 96, 97, 99, 100, 115*

Sampling *19, 37, 53*

Scheffe's test *55*
Screening *31, 86, 106*
Sensory facilities *11, 18, 23*
Significance *53, 61, 65, 69, 76, 77, 82, 83, 85, 97, 102*
Standardization *37*
Statistical analysis *5, 34, 47, 52, 54, 56, 105, 106*
Statistical test *52, 54, 56*
Supplies *11, 13, 19, 23, 25*

Target population *8, 9*
Texture profile *104*
Trained panel *8, 9, 29, 31, 32, 54, 83, 86, 104*
Training *9, 29, 32, 51, 106, 114*
Triangle test *31, 79, 81, 82, 83*
Tukey's test *55, 101*

Untrained panel *7, 8, 29, 30, 62, 65, 70*

Head Office
IDRC, PO Box 8500, Ottawa, Ontario, Canada K1G 3H9

Regional Office for Southeast and East Asia
IDRC, Tanglin PO Box 101, Singapore 9124, Republic of Singapore

Regional Office for South Asia
IDRC, 11 Jor Bagh, New Delhi 110003, India

Regional Office for Eastern and Southern Africa
IDRC, PO Box 62084, Nairobi, Kenya

Regional Office for the Middle East and North Africa
IDRC/CRDI , PO Box 14 Orman, Giza, Cairo, Egypt

Regional Office for West and Central Africa
CRDI, BP 11007, CD Annexe, Dakar, Senegal

Regional Office for Latin America and the Caribbean
CIID, Casilla de Correos 6379, Montevideo, Uruguay

Please direct requests for information about IDRC and its activities to the IDRC office in your region.

IDRC

CANADA